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ABSTRACT

The rate of breakdown of cyclic polyisoprene photoresist has been determined for a range of temperatures between 100-220 °C , two oxygen gas feed rates, three compositions of the feed gas, and three power levels. Calculations based on these data indicate a linear increase in the heat transfer coefficient to the silicon substrate with increasing power, h= 0.00070 - 0.0019 cal./cm^2 -min.-°C, while this coefficient is nearly constant versus oxygen feed rate (i.e. pressure). On the other hand, the activation energy for the polymer degradation process appears to be essentially constant versus power in the 600-800 watt rf power region. However, activation energy undergoes a significant decrease as oxygen feed rate (i.e. pressure) decreases indicating that the rate limiting step for the polymer decomposition is evaporation of chain fragments from the polymer surface. Further confirmation of this conclusion is provided by calculation of the theoretical evaporation energy for the polymer (i.e. isoprene monomer fragments). This polymer evaporation energy is calculated as 5.5 Kcal./gmmole. while the measured activation energy for the degradation process is 2.5-5.5 Kcal./gmmole. A large increase in the activation energy of the process to 14 Kcal./gmmole. was observed at lower rf power levels (400 watts). This increase indicates that a change in the nature of the degradation process oc-

curs in low power oxygen plasmas. This data base on oxygen plasma decomposition of cyclic polyisoprene will be examined even more extensively in the future for further conclusions.

INTRODUCTION AND PROBLEM STATEMENT

In the generation of a diffusion barrier, usually silicon dioxide, for group III-A and V-A dopants, the semiconductor industry uses various photosensitive polymers to create a patterned acid etch barrier for the silicon dioxide. Currently two common photosensitive polymers (photoresists or simply resists) are a cyclized polyisoprene negative-working resist and a novalak (phenol- formaldehyde) resin positive-working resist. The designation negative or positive working is determined by whether the polymer becomes more soluble (positive-working) or less soluble (negative-working) in their respective developing solutions after exposure to ultraviolet light. Developing refers to the process of dissolving the most soluble areas of the polymer, thereby leaving the silicon dioxide surface exposed in the required regions. The developing solution for the polyisoprene resist is xylene while the novalak resin is developed in an aqueous alkali solution. The regions covered by the polymer will act as a barrier to the hydrofluoric acid used to etch the exposed silicon dioxide areas. The reactions which occur in the etching operation are as follows:

$$SiO2\ (s) + 4HF\ (aq.) \quad SiF4\ (g) + 2H2O\ (l)$$

$$SiF4\ (g) + 2HF\ (aq.) \quad H2SiF6\ (aq.)$$

Following the etching of the patterned SiO2 diffusion barrier, the residual resist layer protecting the non-etched areas of the SiO2 must be removed. The present work concerns this operation following the etching step, namely the oxygen plasma removal of the polymer prior to diffusion. Among the methods of negative photoresist removal in current use are J-100 phenolic stripping solution (produced by Indust-Ri-Chem Laboratory), LSI non-phenolic stripping solution (produced by Inland Chemical), sulfuric acid-hydrogen peroxide Caros acid stripping solution, oxygen plasma resist removal, and ozone gas breakdown of the polymer. The first three methods comprise the bulk of industrial usage in microelectronics production , while oxygen plasma usage is a steadily increasing alternative to these major wet chemical methods. The two major methods of positive resist removal are dissolution in acetone, ethyl cellosolve (2ethoxyethanol), or another suitable solvent. Oxygen plasma has not been commercially used for positive resist removal due to the slow observed removal rate. However, positive resist will be included in this study in an attempt to discover the cause of the observed slow rate of removal.

The oxygen plasma removal method which will be examined in this paper consists of exposing the photosensitive polymer (negative or positive) silicon wafer to an oxygen gas activated by a radio frequency field so that the gas becomes a plasma of oxygen ions and electrons. The removal

occurs under nearly constant pressure vacuum conditions during the course of the photoresist breakdown. Although this plasma procedure is being used commercially, little is known of the plasma-polymer reaction kinetics and mechanisms. The process appears to be oxidation of the nitrogen, carbon, hydrogen, and oxygen in the polymers to form volatile gases such as CO, CO2, (NO)x, NO2, H2O, OH-, O2, and O3. The nitrogen molecules are reaction products only of the novalak resin polymers (positive resists) which contain nitrogen and oxygen groups. The cyclic polyisoprene polymers (negative resists) yield exclusively carbon and hydrogen containing reaction products; any ozone present is generated by the action of the rf field on the oxygen gas reactant.

The scope of this paper will be to determine the reaction rate and possibly the kinetics for the breakdown of the two types of polymers; of major interest will be cyclic polyisoprene and novalak resin (phenol-formaldehyde) photoresists.

THEORY-REVIEW OF THE LITERATURE

In the study of heterogeneous chemical reactions, the usual analysis entails the determination of whether diffusion or chemical reaction is the controlling step in the overall rate. When reaction rate is controlling, the study would include an analysis of the temperature dependence of the rate which usually takes the form of an Arrhenius type equation,

$$dC/dt = Rate = A*exp(-E/RT) * f(C) \qquad (1)$$

Using this equation , mass balances, and kinetic data (e.g. C vs. t , and Rate vs. T), the value of unknowns E and A can be calculated for a specific reaction. From this complete knowledge of eqn. (1), the reactor design can be made. However, researchers report that reaction processes in a radio frequency plasma do not rigorously fit this method of analysis [1].

The number of oxygen ion species in the plasma has been examined by several researchers [2-11]. Hollahan and Carlson note the presence of: O+, (O2)+, O−, (O2)−, O(3P), O2(1Δg), and electrons [12]. The positive ions and free electrons are formed by dissociation due to the oscillating radio frequency field, whereas the negative ions and metastable species are products of electron-neutral ion collisions. The oxidation reaction has been attributed mainly to the metastable species (i.e. O(3P) and O2(1Δg)) because of their

long lifetimes compared to the charged ion species [12,7,4]. Additionally, to complicate the analysis, Hansen et. al. have found experimentally that electron bombardment of polymers increases the rate of decomposition by the metastable ions [2]. Since electrons are also an active specie in a plasma, Hansen's finding indicates that many species participate in the polymer oxidation reaction in addition to the two metastable oxygen species . Therefore, all the species in an oxygen plasma have a role in the reaction, since even non-reacting ions affect the velocities of the active species.

Activation of polymer surfaces by electron and ion bombardment has been an area of extensive research over the last two decades [12-18]. One major purpose of this work was to analyze the reasons for the improvement of adhesive bonding and printability on polymer surfaces treated in either a neutral ion or oxygen plasma. Some of this research investigated oxygen plasmas to achieve both improved surface properties and bulk electrical characteristics [18-21]. The work with plasma treated polymer surfaces led to speculation on whether the surface contained large numbers of free radicals which then degraded to form hydroxy and peroxy compounds on exposure to air [4,12-15]. These peroxy compounds then might react to form a denser surface layer by cross-linking than existed in the bulk polymer, thereby improving the chemical resistance and bondibility of the polymer.

Since the Arrhenius form of the rate equation is not applicable to a plasma reaction, other mathematical descriptions of the reaction must be examined. The Boltzman equation which uses a Maxwellian distribution of charged specie energies might be used to describe the non-reacting plasma [22]. However, even for non-reacting gas plasmas the Boltzman equation would be so complex that lengthy computer solutions would be required. This solution would then be limited to a non-reacting, "equilibrium" region of the plasma away from the reactor walls. Another mathematical description that might be attempted would be to apply quantum mechanics to the plasma reactions. An extensive discussion of this method is presented by Venugopalan [23]. Hollahan and Bell have also presented an excellent summary of the possible mathematical descriptions of a plasma [24]. Although some insight into plasma processes can be obtained from these descriptions, they are far too limitted to provide an understanding of the complex interactions of plasma reactions.

With a mathematical description of the oxygen plasma reactions being currently incomplete, chemical engineering kinetic data must be taken and analyzed to describe the plasma reaction process in terms of engineering concepts (i.e. boundary layers, film coefficients). Also, the overall rate of polymer removal can be experimentally determined. This removal rate can then be studied as a function of power

level, pressure(O2 flow), and O2 concentration in a neutral gas. During these analyses of removal rate, the temperature of the silicon wafers should be monitored so that the heating effect of the ion energy transfer can be described. Also, if the polymer phase reactions rather than the plasma reactions are rate controlling in this process, then an Arrhenius type of analysis may be performed on these polymer reactions. Whether plasma or polymer reactions control the process, meaningful determinations can be made of the concentration, temperature, pressure, and wafer loading effects on the reaction rate.

A very good overview of the recent developments in plasma polymerization and plasma polymer interactions was completed by Havens et. al. [33]. However, in order to obtain the specific background information on oxygen plasma-polymer reactions, the review in Hollahan and Bell's book is recommended [25]. This more detailled review was written by Martin Hudis. Hudis lists the following polymer oxidation reactions as characteristic in an oxygen plasma [26],

$$R\text{-}H + O\cdot \longrightarrow R'\cdot + R''\text{-}O\cdot \qquad (2)$$

$$R\text{-}H + 2O\cdot \longrightarrow R\cdot + H\cdot + O2 \qquad (3)$$

$$R\text{-}H + uv \longrightarrow R\cdot + H\cdot \qquad (4)$$

$$R\cdot + O2 \longrightarrow R\text{-}O\text{-}O\cdot \qquad (5)$$

$$R\text{-}O\text{-}O\cdot + R'\text{-}H \longrightarrow R\text{-}O\text{-}O\text{-}H + R'\cdot \qquad (6)$$

$$2\ R\text{-}O\text{-}O\text{-}H \longrightarrow R{=}O + H2O + R\text{-}O\text{-}O\cdot \qquad (7)$$

$$R\text{-}O\cdot + R'\text{-}H \longrightarrow R\cdot + R'\text{-}O\text{-}H \quad (8)$$

$$R\text{-}H + O\text{-}H\cdot \longrightarrow R\cdot + H2O \quad (9)$$

$$R\cdot + O\cdot \longrightarrow R\text{-}O\cdot \quad (10)$$

The most important findings cited in this review are those of Hansen et. al. whose work with eight polymers in an oxygen plasma revealed that the major mechanism of polymer degradation was ablation. Hansen found that for these eight polymers, the weight loss was a linear function of the time of exposure to the plasma and that the slope of this line was determined by the polymer structure. Hudis states,

> " Ablation appears to be an exclusive property of oxygen containing plasmas. Ablation also causes changes in surface morphology. Small molecular weight degradation products which are covalently bonded to the surface migrate around the surface, producing small bumps which have been detected using a scanning electron microscopy (sic)." [27]

The present research will attempt to determine if the degradation mechanism of cyclic polyisoprene and novalak resin resists is by chemical reaction, ablation, or a combination of these two processes.

Also of interest is the formation of multi-ringed compounds, such as naphthalene, from both linear and cyclic olefins during plasma reactions. This work is cited in an article by Harald Suhr in Hollahan and Bell [28]. It is possible that some of the reactions at the polymer surface are ring formations or ring de-saturations. Hydrogen abstraction which would create ring de-saturation in cyclic-polyisoprene is referred to in the literature as a common

plasma reaction because of the low dissociation energy associated with this process [18, 30, 29].

THEORY-DESCRIPTIVE EQUATIONS

Since the system being used in this study operates in a transient mode during most of the reaction, the descriptive equations which must be used are those for a semi-batch reactor. The material balance for each component is [31],

$$(\dot{v}*C_i)_f - (\dot{v}*C_i)_e + V_r*R = V_t*(dC_i/dt) \qquad (11)$$

where R =reaction rate, gmmoles/liter-minute, of component i

$\dot{v}$= volumetric flow rate , liters/minute

V= volume(reactor,r, or total, t)

f,e= subscripts designating feed or exit points

C_i= concentration in gmmoles/liter of component i

t = time

In eqn.(11), the first term accounts for the molar rate of component (i) entering the reactor, the second accounts for (i) leaving the reactor, the third accounts for (i) formed by reaction, and the term on the right hand side accounts for the overall rate of change in concentration of (i) in the system with time. From the same source, the energy balance equation for the reactor is [32],

$$-\Delta H*R*V_r*dt + (\dot{v}*C_t)_f*CP_f*(T_o-T) = N_t*CP*dT + U*AR*(T-T_s)*dt \qquad (12)$$

where ΔH= heat of reaction, kcal/gmmole
CP = heat capacity of the feed or reaction mixture, kcal/gmmole-^oK

T = temperature, ^{0}K

N = total gmmoles of reaction mixture

AR= area for heat transfer to the surroundings

U = overall heat transfer coefficient, $kcal/cm^{2}$-hr-^{0}K

In equation (12), the first term accounts for the heat of reaction , the second for heating the feed, and on the right hand side of the equation, the first term accounts for heating of the reaction mixture, and the second for heat loss to the surroundings.

In order to simplify solution of equations (11) and (12), several independent relationships were established. First, since the vacuum pump operates as a positive displacement pump down to about 0.01 torr, a linear or quadratic function should exist between volumetric flow rate and pressure . This relationship may be empirically determined, and it then becomes an additional equation eliminating one unknown variable. A slight complication arises in determining this relationship, however, because the thermal conductivity type of pressure gauge used is composition dependent due to the differing thermal conductivities of the reaction gases. Therefore, an iteration procedure described in Appendix I was required to determine the actual total pressure in the concentration measuring cell.

Once the total pressure has been determined, the volumetric flow rate leaving the system can be calculated

using the flow-pressure relationship described above. Since the exit concentration of the product gases will be monitored with time and no product gases enter the system with the oxygen feed, the first two terms in eqn. (11) will be known. Only two terms remain unknown in eqn. (11), the reaction rate and the change of concentration with time in the whole system, dC_i / dt. However, since no reaction occurs outside the reactor, then the exhaust gas measuring apparatus can be included in the system for calculation purposes. Now the appropriate smooth function can be fitted to the exhaust gas concentration-time data and analytically differentiated to give, dC_i / dt. Thus with these relationships established empirically, a direct calculation of the plasma reaction rate can be made.

The scope of the present work does not include a full thermal study of the plasma reactor system. Therefore, no solution of eqn. (12) will be examined.

OBJECTIVE OF THE RESEARCH

The purpose of this study is to provide an understanding of those properties of an oxidizing plasma which are of interest to the chemical engineer in the description of polymer degradation. The experimental work will seek to determine the rates of breakdown of cyclic polyisoprene and novalak resin resist in this plasma. Variables affecting the rate to be examined are: radio frequency (rf) power, total pressure f(O2 flow rate), oxygen concentration in a neutral gas, and initial polymer load (number of coated wafers) in the reactor.

Since polymer degradation in an oxygen plasma has been termed "ablative" rather than reactive, this research will attempt to determine which mode is applicable to cyclic polyisoprene and novalak resin resists. whichever mode is applicable, this work seeks to utilize the results of the experiments to improve the reactor and process design not only for oxygen plasma degradation of polymers, but also similar plasma processes in the semiconductor industry.

EQUIPMENT DESCRIPTION

Background

Since the overriding consideration in this study is that the reaction occurs in a vacuum, the optimum equipment for the study of the reaction products is a sampling residual gas analyzer (RGA, or mass spectrometer). This analyzer would not only permit examination of the products, but also the long-lived intermediates in the reaction. High cost and lack of availability eliminated use of the optimum equipment (most plasma research is performed with some variant of the mass spectrometer). The alternatives to the RGA with the exception of emission spectroscopy all take a step back from the reaction intermediates themselves to the reaction products: CO_2, H_2O, and CO. The exploration of workable analytical techniques for examining the concentration of these reaction products versus time involved a literature search of CO_2, H_2O, and CO detection techniques. Among the techniques available are sonic velocity of the exhaust gas, conductance of a solution in which the CO_2 is absorbed, gaseous ionization, sound and ultrasound attenuation, and infrared spectroscopy. Since the infrared spectrometer alone could monitor all of the expected reaction products including the N-O family of gases from the breakdown of the novalak resin resist, it was chosen as the detection instrument for studying the exhaust gases.

Reactor

The apparatus (see Appendix III for diagrams) used for this study was a production model International Plasma Corporation photoresist stripper, model no. 2100. The radio frequency (rf) oscillation of 13.56 megahertz is capacitively coupled and has a maximum forward power of 1000 watts. Balance controls permit adjustment of the rf circuit to maintain minimum reflected power when varying loads are present in the reaction chamber. Cycle times, gas supplies, and power levels were set up on the IPC PM-508 controller. The reactor has two quartz reaction chambers (6" inches diameter by 13" inches long). Oxygen flows into the bottom of the reaction chamber and exhaust gases are drawn out the top by vacuum, supplied by a 17 cfm Welch oil-diffusion pump. During all of the experiments, the wafer diameter was parallel to the reactor diameter.

Pressure Gauges

Reaction chamber pressure was measured with a Hastings-Raydist model DV-4DM thermocouple gauge installed in the exhaust line downstream from the chamber. Since the gauge was factory calibrated for 0-20 mm Hg (torr) of air, the conversion tables and nomograph to read the correct pressure of a different gas (e.g. O_2, CO_2, H_2O) are reproduced in Appendix I Tables AP I-1,2,and 3. The meter for the vacuum gauge was readable near experimental conditions as 7.0 ± 0.1 torr. Since the meter has a log scale, readable precision was better below 7 torr and somewhat worse above it.

Due to the remote location of the 17 CFM pump under the experimental conditions of this study , the minimum pressure (no O2 flow) obtainable was 0.6 torr. The experimental pressure of 3.0 torr was obtained with an oxygen flow of 55 cc/minute. Under normal production conditions, the pump is typically connected closer to the reaction chamber exhaust and can attain a pressure as low as 0.1 torr.

Flow Controllers

Initially, calibrated Brooks rotameters were used for oxygen and carbon dioxide flow measurement during the setup of the experimental apparatus. However, since the gas density around the float was variable in the vacuum flow system, the only way to obtain absolute flow rates with the rotameters was to continually solve the Stokes terminal velocity equation. A new means of flow measurement was obviously needed. Therefore, two Tylan Corp. model FCS-100 mass flow controllers were obtained. Each controller was factory calibrated for a flow of 0-200 cc/minute of hydrogen at STP (the appropriate conversion factors for other gases is contained in Appendix IV). The readable precision of the controller was ± 0.5 cc/minute over the entire 0-200 range. The principle of operation of the controller is differential thermal conductivity (see Appendix IV-A). One controller was used for oxygen flow while the other was used for CO2 flow during the calibration runs. The oxygen and carbon dioxide were supplied to the controller at 5 psig.

Temperature-Thermocouples and Pyrometer

Silicon wafer temperature measurements were made using two devices, a thermocouple or an infrared pyrometer. The thermocouple was a Simpson model 388-3L iron-constantan type with plexiglas protection of the metal leads. A Hewlett-Packard digital voltmeter was used to read the thermocouple signal with the high frequency rf pickup appropriately attenuated by the common mode rejection circuit shown in Fig. AP III-2. This thermocouple was inserted into the reaction chamber through an epoxy-sealed tee on a special quartz adapter for the exhaust line. The junction bead of the thermocouple was protected from the rf field by the aluminum oxide binder (Insa-Lute adhesive cement no. 1, Sauerreisen Cement Co.) which was used to attach it to the silicon wafer. An observation developed from the measurements with this thermocouple . When the wafer-thermocouple probe was placed parallel to the reactor diameter (i.e. perpendicular to the rf electrodes), no rf interference (pickup) ocurred in the measurement. However, when the probe was perpendicular to the reactor diameter, a +2.3 millivolt jump in the thermoeouple signal ocurred whenever the rf power was turned on at 800 watts. This rf pickup is demonstrated by the large gap in the two curves of thermocouple data appearing on Fig. AP II-1. A second identical thermocouple also was inserted through the adapter into the exhaust line to obtain exhaust gas temperatures.

Although some data were taken with the thermocouples, the majority of the silicon wafer temperature data were taken with an IR Industries model TD-7B infrared pyrometer. It operates by measuring the intensity of the infrared radation being emitted by an object in the 1.75-2.7 micron region of the spectrum. No significant loss of infrared radation is caused by the quartz window on the reactor. In comparing the pyrometer readings with the earlier thermocouple temperature measurements, it was noted that the thermocouple values were identical to the pyrometer temperatures.

Gas Concentration-Infrared Spectrometer

Measurement of the exhaust gas concentrations of H2O, CO2, and CO was made by passing the exhaust through a Beckman model 22557 variable pathlength (0.01 to 10 meter) cell which was placed in the sample beam of a Perkin-Elmer model 457 double beam infrared spectrometer. Since both a separate Nernst glower and a mirror were used in the optical path of the sample beam, a diagram of this instruments layout is included in Fig. AP III-1. A preliminary examination of the exhaust gas to identify the components, revealed that only CO2 and H2O were present. Therefore, the spectrometer wavelength was able to be fixed at the major CO2 absorbtion peak at 2349 cm^{-1} (4.3 microns) for the polyisoprene exhaust gas measurements. The Nernst glower for the sample beam was supplied power by a 6.3 Volt, 10 Amp filament transformer controlled by a 115 VAC variac. The transformer delivered

approximately 4V at 10 A to the glower. In order to minimize the effects of changes in the atmospheric CO2 concentration on the transmittance readings, the entire spectrometer and gas cell were enclosed in a plexiglas box purged with nitrogen.

PROCEDURE - CALIBRATIONS

Temperature

In order to obtain close to absolute temperature calibration for these experiments, the melting points of pure chemicals were used . A detailed description of the calibration technique is given in Appendix II. The pertinent relationships derived from the calibration are:

For the thermocouples,

$$T_{\text{hot chuck}}\ (^{\circ}C) = 1.065 * T_{\text{thermocouple}}\ (^{\circ}C) \quad (13)$$

$$T_{\text{actual}}\ (^{\circ}C) = 1.005 * T_{\text{hot chuck}} + 7.0165 \quad (14)$$

$$T_{\text{actual}}\ (^{\circ}C) = 1.07 * T_{\text{thermocouple}} + 7.0165 \quad (15)$$

For the infrared pyrometer,

$$T_{\text{hot chuck}}\ (^{\circ}C) = 0.9922 * T_{\text{pyrometer}}\ (^{\circ}C) + 0.1318 \quad (16)$$

combining equation (14) and (16),

$$T_{\text{actual}}\ (^{\circ}C) = 0.997 * T_{\text{pyrometer}} + 7.149 \quad (17)$$

Pressure

Using the closest pressure measurement technique to absolute for the 3 torr region of this experiment, the two thermocouple pressure gauges were calibrated to a McLeod gauge by the technique described in Appendix I. From this calibration work, several important relationships were developed for oxygen pressure in the system:

$$P_{\text{gas cell (torr)}} = 0.4969 * P_{\text{exhaust gauge (torr)}} + .0027 \quad (18)$$

$$P_{reactor\ (torr)} = 0.5960 * P_{exhaust\ gauge\ (torr)} - .0856 \quad (19)$$

Although these relationships apply only to oxygen, they are very important for deriving the actual total pressure for the multicomponent mixture of oxygen, carbon dioxide, and water created in the experiment. A complete description of the iteration technique used to obtain the total pressure is contained in Appendix I-A.

Flow

Absolute gas flow calibration can be done by displacing a measured volume of liquid in an interval of time long enough to reduce the error to a small amount. The gas should be insoluble and unreactive in this liquid, therefore, mercury is often used. The calibration of the two mass flow controllers used in this experiment is described in Appendix IV. Although the controllers were claimed to be factory calibrated, the readings from them were approximately 45% low. The relationships developed are,

$$\dot{v}_{O2\ (cc/min.)} = 1.38 * \dot{v}_{reading\ (cc/min.)} * [1.0] \quad (20)$$

$$\dot{v}_{carbon\ dioxide} = 1.48 * \dot{v}_{reading} * [0.74] \quad (21)$$

The numbers in the square brackets are the correction factors from the manufacturer's literature, Table AP IV-1, to account for the different properties of the two gases.

Another important flow relationship needed for the solution of the system equations (see Descriptive Equations) was flow vs. pressure for the IR gas cell. Since at the low pressures involved in the experiment , the gases should all behave as ideal gases, oxygen was chosen for the actual measurement used in the experimental calculations. However, as a precaution pressure vs. flow data were also taken for CO2 and H2O. These raw data were reduced using the calibration equations for flow and pressure previously developed. A plot of the oxygen data appears on Fig. AP IV-4 while all of the data are charted on Table AP IV-5 and plotted on Fig. AP IV-6. For easy use in the calculations, a quadratic equation was fitted to the oxygen data, (Table AP IV-7)

$$\dot{v}\ (cc/min.) = -7.993 + 5.329 * Pir\ cell + 4.789 * Pir\ cell \qquad (21\text{-}A)$$

where Pir cell = actual gas cell pressure, torr.

Absorbance-Transmittance

In quantitative infrared analysis, large sections of many books are dedicated to equipment calibration due to the low energies being measured. Many factors can lead to inaccuracies because of the numerous operating components in both the experimental and measuring system. Gases may be adsorbed on the measuring cell walls and mirrors, mirrors may be dirty and scatter the infrared signal, mirrors may be misaligned, amplifiers and electronic components may fail

causing signal drift. However, many of these problems can be avoided through careful rechecking of baselines and full scale deflection points during the course of the experimental work. In Appendix V, the details of the calibration measurements are discussed.

The relationship between carbon dioxide concentration and absorbance obtained from these quantitative infrared measurements was,

$$C_{co2}\ (\text{gmmoles/liter}) = (8.022E\text{-}4) * A_{gas} - (2.139E\text{-}5) \quad (22)$$

where A gas = per cent absorbance of the gas

PROCEDURE - PRELIMINARY EXPERIMENTS

Temperature Measurements

Initially, the cause of the wafer temperature rise was unknown. However, since the lightly doped ($1*10^{15}$ atoms/cc) silicon used will not couple to the rf field, rf heating of the wafers cannot occur. Therefore, the activated ions and electrons must transfer energy to the wafers to cause the temperature rise. Since this is the mechanism of energy transfer, the most direct measurement technique would be a surface temperature method because the polymer removal is a surface reaction in conjunction with surface heating of both the polymer and substrate silicon. Thermistors, thermocouples, and infrared pyrometers might be used for the

measurement. However, since rf is present, thermistors cannot be used because the carbon sensor would couple with the rf field, absorbing energy and giving a false reading. However, thermocouples could be used if the metallic junction could be shielded from the rf. To test the use of thermocouples, one was attached to a silicon wafer as described earlier, and temperature vs. time was measured at an rf power of 800 watts (each reaction chamber was loaded with 50 wafers to simulate normal operation). The data from this experiment are plotted on Fig. AP II-1. The exponential equation which describes these curves is the solution to the heat transfer problem of an object with negligible surface resistance to heat transfer being suddenly immersed in an ambient of higher temperature. This finding is completely consistent with ion-electron bombardment as the mechanism for energy transfer to the wafer. The equation is shown below [39],

$$(T_{gas} - T) / (T_{gas} - T(0)) = \exp(-N * t) \qquad (23)$$

where T= temperature of the gas ambient or the wafer, °K

N = (AR*h/ ρ *CP*V) silicon wafers, a constant

AR= surface area of the wafer, cm^2

V= volume of the wafer, cm^3

CP= heat capacity of the silicon, calories/gram-°K

h= heat transfer coefficient to the silicon, cal./cm^2-min.-°K

$T(0)$ = wafer initial temperature, ^{o}K

The constants for this equation are listed in Table 24. A second thermocouple was used to measure exhaust gas temperature downstream from the reactor. This thermocouple was monitored as the pressure in the reactor was varied and provided a plot of steady-state exhaust temperature vs. pressure, Fig. APII-6. The higher exhaust temperature at lower pressure is caused by expansion of the plasma into the exhaust line which increases the energy transfer from the longer lived excited species to the thermocouple junction. Of course, the expansion of the plasma is due to the reduced collision frequency or longer mean free path at low pressures.

This thermocouple system survived about twenty trial reaction runs after which the fiberglas covering on the leads finally disintegrated. The exposed metal coupled directly to the rf field, glowed red hot, and conducted heat to the junction, ending the feasibility of thermocouple temperature measurement for the set of primary experimental runs.

In order to obtain long term reproducibility in the wafer temperature measurement, an infrared pyrometer was obtained. The temperature scale on this pyrometer began at 110 ^{o}C. Therefore, the initial heating of the wafer could not be monitored using this instrument. However, since the equation

for the temperature rise is known, eqn.(23), it was used to estimate this initial temperature rise region by calculating the eqn.(23) constants from the actual data obtained above 710 °C.

Concentration Measurement

Using the spectrometer system previously described, a full infrared spectrum was run on the exhaust gases at a pathlength of 6.4 meters. Since the characteristic CO bands between 4.5 and 4.9 microns were absent, the CO gas concentration was eliminated from experimental consideration. The implication of this finding is that either the 800 watt plasma is energetic enough to completely oxidize all reaction products or that the nature of the reaction precludes formation of CO.

Continuing the check on variables affecting the CO2 concentration measurement , the possibility of H2O vapor absorbtion interfering with the CO2 absorbtion at 2349 cm^{-1} was examined. Since data had already been taken on IR transmittance vs. time for three different groups of product wafers, Fig. AP V-3, a calculation was performed to estimate the total grammoles of CO2 which had been produced. From this estimate the CO2 concentration corresponding to the minimum transmittance (72.5%) was calculated and found to be $1.345*10^{-4}$ gmmoles/liter. After the absorbance-transmittance calibration was complete, the concentration corresponding to 72,5% transmittance (14% absorbance) was found to be $1.0*10^{-4}$

gmmoles/liter. The close agreement of these values indicates that there was no H2O interference with the CO2 concentration measurement. As a final precaution, water vapor was drawn through the gas cell while the transmittance was monitored. No absorbtion was observed.

One significant problem with constructing the calibration curve appeared when the data were plotted. When a least square straight line was fitted to the data, the zero concentration point intercepted the absorbance axis at +2.3% rather than 0%. No experimental or theoretical explanation of this offset was apparent, although many possible explanations can be found in the literature on infrared quantitative analysis. The present research will treat this offset value as zero CO2 concentration.

RESULTS

Background to the Primary Experiments

In order to determine the removal rate of photoresist from silicon wafers, the information needed was the total weight loss of photoresist for the time exposed to the plasma. Also, to define when the weight was lost during the cycle, a plot of CO2 concentration in the exhaust gas vs. time was required . Since the integral of the CO2 concentration with time should correspond directly to the measured total weight loss, these data act as an internal check on the consistency between these two measurements. The weight loss was obtained simply by weighing the silicon wafers coated with photoresist both before and after each plasma run. Measurement of the CO2 concentration was made with the Perkin-Elmer spectrometer system and required simultaneous reading of the transmittance and the total pressure of the reaction chambers. Ten 3" diameter wafers coated on each side with resist were placed in each of the reaction chambers. The quartz rack holding the wafers had a wafer to wafer spacing of 0.25 inches. The silicon wafers were oxidized on one side to simulate normal product. To weigh the wafers, they were stacked on the pan of the Mettler balance described earlier. An additional parameter, the wafer temperature, was monitored as a measure of the energy input to the resist surface. In order to prevent inaccuracies in the

relationship between carbon dioxide formation and polymer weight loss, most of the solvents in the resist were driven off by vacuum and baking treatments (160°C) before the experiments began.

Primary Experiments

The experiments to determine overall removal rates of the resists required measurement of: weight loss vs. rf power and time, pressure (pressure is controlled by the oxygen feed rate), initial polymer load (number of coated wafers), and the per cent oxygen in the feed. In the first category of experiments, four runs of 25-44 minutes duration were made at 200, 400, 600, and 800 watts rf power. Longer times were used for the 200, and 400 watt runs in order to remove enough resist to reduce the error in the weight loss and CO_2 concentration measurements. Ten coated wafers were placed in each chamber and the oxygen feed rate was held at 55 cc/minute. Data from these runs are charted on Tables 1-4 and plotted on Figs. 5-9. For the second set of experiments two runs were made at 800 watts and a 27 cc/minute oxygen feed rate. Data on the time variance of absorbance, pressure, and temperature at this new oxygen feed rate are charted on Tables 10 and 11 and plotted on Figs. 5-9. During the third experiment, the power was held constant at 800 watts and the feed rate at 27 cc/minute, while the time was varied for each run. The weight loss, wafer temperature, and total pressure were monitored for run times of 1, 2, 3,

4, 5, 7, 8, 10, 12, 16, 18, and 24 minutes. The chart of weight loss vs. time data is Table 12 and Figs. 12a, 12b, 12c. The next experiment measured the weight loss from 2, 6, and 10 coated wafers per chamber while time, power, and feed rate were held constant at 20 minutes, 800 watts, and 55 cc/minute, respectively. Table 13 presents the details of these data and weight loss vs. load is plotted in Fig. 14. In addition to using pure oxygen as the reaction gas for the negative resist removal measurements, several measurements were taken of polymer removal rates for 0, 12.5, and 22 % oxygen in nitrogen which acts as a neutral gas. The experiments were performed at 800 watts of power and weight loss, wafer temperature, and pressure were monitored. A plot of the weight loss data is presented in Figure 15. The small positive removal rate observed in the pure nitrogen run was caused by a small amount of air leakage into the system.

Positive Resist

The attempt to perform these same five primary experiments with positive resist failed. Although three runs were made in which all parameters were monitored, a rapid pressure rise developed about eight minutes into each run. This effect brought the run to a halt, since the high pressures could not be measured precisely and the plasma could barely be maintained. Consequently, novalak resin resist stripping was dropped from this project. It was suspected initially that a byproduct of novalak breakdown was reacting with the

silicone rubber reactor seals causing an air leak. However, the seals suffered no damage because this supposed air leak was absent during subsequent negative resist runs and vacuum testing. Therefore, an explanation based on the novalak reaction itself was sought. One possible cause of enhanced reaction of positive resist is the breakdown of the naphthoquinone diazide sensitizer to ketene releasing nitrogen followed by the rapid breakdown of the ketene releasing carbon dioxide. In addition, the oxygen content of both the novalak resin ($C_{71}H_{79}O_9$) and the sensitizer ($C_{23}H_{14}O_7S$) is very high compared to the nearly pure hydrocarbon structure of the polyisoprene. Therefore, this positive resist structure should breakdown more rapidly than the polyisoprene, yielding a larger pressure rise.

> " Fluorocarbon polymers have the smallest ablation rate. Hydrogen polymers have a larger ablation rate and hydrocarbon polymers containing oxygen have the largest ablation rate." [34]

This general observation by Hudis runs contrary to the observed slow removal rate of positive resist and the data in D'Allelio and Parker's book which attest to the excellent resistance to removal of the novalak resin family of polymers. [35] Recent attempts to recreate this pressure rise effect have failed, leaving the phenomenon even more perplexing. The scant data gathered from these three runs is presented in Tables 16-18 for completeness.

TABLE 1

RUN NUMBER 1
NO. DATA POINTS 25
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 800.0000
02 FEED RATE 55.199966 CC/MINUTE
BASELINE TRANSMITTANCE 0.8650

THE DATA ON THIS PAGE WAS REDUCED USING THECALIBRATION RELATIONS DEVELOPED EARLIER IN THIS PROGRAM
FLOW NORMALIZATION FACTOR WAS, 1.30996

THE MEASURED WT. LOSS IS 0.1689 GRAMS THE CO2 LOSS CALCULATED FROM TRANSMITTANCE DATA IS 0.5464 GRAMS

TIME (MINUTES)	ABSORBANCE	TRANSMIT--TANCE	RXN-RATE GRAMMOLES/ LITER-MIN.	IR CELL PRESSURE (TORR)	CO2 MOLE FRACTION	CO2 LOSS GRAMS PER MINUTE	TOTAL CO2 LOSS (GRAMS)	WAFER TEMPERATURE (DEGREES C)	D(02)/DT GRAMMOLES/ LITER-MIN.
0.1000E+01	0.2853E-01	0.9364E+00	0.1965E-05	0.3219E+01	0.8676E-02	0.6956E-03	0.6956E-03	0.0	0.1982E-04
0.2000E+01	0.4492E-01	0.9017E+00	0.1328E-04	0.3164E+01	0.8663E-01	0.6709E-02	0.7405E-02	0.0	0.2547E-04
0.3000E+01	0.4771E-01	0.8960E+00	0.1554E-04	0.3245E+01	0.9737E-01	0.7932E-02	0.1534E-01	0.1208E+03	0.2168E-04
0.4000E+01	0.5222E-01	0.8867E+00	0.1877E-04	0.3259E+01	0.1177E+00	0.9671E-02	0.2501E-01	0.1268E+03	0.2174E-04
0.5000E+01	0.5620E-01	0.8786E+00	0.2165E-04	0.3271E+01	0.1356E+00	0.1122E-01	0.3623E-01	0.1348E+03	0.2179E-04
0.6000E+01	0.5907E-01	0.8728E+00	0.2351E-04	0.3248E+01	0.1498E+00	0.1222E-01	0.4845E-01	0.1478E+03	0.2355E-04
0.7000E+01	0.6778E-01	0.8555E+00	0.3010E-04	0.3293E+01	0.1875E+00	0.1572E-01	0.6417E-01	0.1567E+03	0.2262E-04
0.8000E+01	0.7369E-01	0.8439E+00	0.3462E-04	0.3321E+01	0.2126E+00	0.1813E-01	0.8230E-01	0.1667E+03	0.2215E-04
0.9000E+01	0.7968E-01	0.8324E+00	0.3940E-04	0.3360E+01	0.2369E+00	0.2067E-01	0.1030E+00	0.1737E+03	0.2114E-04
0.1000E+02	0.8576E-01	0.8208E+00	0.4341E-04	0.3325E+01	0.2669E+00	0.2280E-01	0.1258E+00	0.1807E+03	0.2405E-04
0.1100E+02	0.9192E-01	0.8092E+00	0.4808E-04	0.3338E+01	0.2935E+00	0.2528E-01	0.1510E+00	0.1966E+03	0.2440E-04
0.1200E+02	0.9192E-01	0.8092E+00	0.4873E-04	0.3387E+01	0.2893E+00	0.2563E-01	0.1767E+00	0.2006E+03	0.2188E-04
0.1300E+02	0.9192E-01	0.8092E+00	0.4871E-04	0.3387E+01	0.2893E+00	0.2563E-01	0.2023E+00	0.2046E+03	0.2190E-04
0.1400E+02	0.9192E-01	0.8092E+00	0.4869E-04	0.3387E+01	0.2893E+00	0.2563E-01	0.2280E+00	0.2066E+03	0.2191E-04
0.1500E+02	0.9503E-01	0.8035E+00	0.5144E-04	0.3417E+01	0.3004E+00	0.2709E-01	0.2550E+00	0.2106E+03	0.2084E-04
0.1600E+02	0.9503E-01	0.8035E+00	0.5142E-04	0.3417E+01	0.3004E+00	0.2709E-01	0.2821E+00	0.2126E+03	0.2085E-04
0.1700E+02	0.1013E+00	0.7919E+00	0.5572E-04	0.3391E+01	0.3306E+00	0.2937E-01	0.3115E+00	0.2146E+03	0.2333E-04
0.1800E+02	0.1013E+00	0.7919E+00	0.5571E-04	0.3391E+01	0.3306E+00	0.2937E-01	0.3409E+00	0.2166E+03	0.2333E-04
0.1900E+02	0.1013E+00	0.7919E+00	0.5570E-04	0.3391E+01	0.3306E+00	0.2937E-01	0.3702E+00	0.2186E+03	0.2334E-04
0.2000E+02	0.1013E+00	0.7919E+00	0.5569E-04	0.3391E+01	0.3306E+00	0.2937E-01	0.3996E+00	0.2205E+03	0.2335E-04
0.2100E+02	0.1013E+00	0.7919E+00	0.5568E-04	0.3391E+01	0.3306E+00	0.2937E-01	0.4290E+00	0.2215E+03	0.2336E-04
0.2200E+02	0.1013E+00	0.7919E+00	0.5568E-04	0.3391E+01	0.3306E+00	0.2937E-01	0.4583E+00	0.2225E+03	0.2336E-04
0.2300E+02	0.1013E+00	0.7919E+00	0.5567E-04	0.3391E+01	0.3306E+00	0.2937E-01	0.4877E+00	0.2235E+03	0.2337E-04
0.2400E+02	0.1013E+00	0.7919E+00	0.5566E-04	0.3391E+01	0.3306E+00	0.2937E-01	0.5171E+00	0.2245E+03	0.2337E-04
0.2500E+02	0.1013E+00	0.7919E+00	0.5566E-04	0.3391E+01	0.3306E+00	0.2937E-01	0.5464E+00	0.2255E+03	0.2337E-04

ABSORBANCE
FOR RUN NO. 1 THE COFFICIENT VALUES ARE A=0.9352E-01 B=0.1163E+00 Y0=0.2583E-01

PRESSURE IR CELL
FOR RUN NO. 1 THE COFFICIENT VALUES ARE A=0.7848E+00 B=0.1133E+00 Y0=0.3183E+01

TEMPERATURE
FOR RUN NO. 1 THE COFFICIENT VALUES ARE A=0.1725E+03 B=0.1057E+00 Y0=0.6960E+02

BEST QUADRATIC FIT OF THE TOTAL CO2 LOSS(GRAMS) WITH TIME GIVES COEFS. A=-.1719E-01 B=0.9501E-02 C=0.5472E-03

TABLE 2

RUN NUMBER 2
NO. DATA POINTS 20
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 200.0000
O2 FEED RATE 55.199966 CC/MINUTE
BASELINE TRANSMITTANCE 0.8950

THE DATA ON THIS PAGE WAS REDUCED USING THECALIBRATION RELATIONS DEVELOPED EARLIER IN THIS PROGRAM
FLOW NORMALIZATION FACTOR WAS, 1.00000

THE MEASURED WT. LOSS IS 0.0525 GRAMS THE CO2 LOSS CALCULATED FROM TRANSMITTANCE DATA IS 0.0 GRAMS

TIME (MINUTES)	ABSORBANCE	TRANSMIT--TANCE	RXN-RATE GRAMMOLES/ LITER-MIN.	IR CELL PRESSURE (TORR)	CO2 MOLE FRACTION	CO2 LOSS GRAMS PER MINUTE	TOTAL CO2 LOSS (GRAMS)	WAFER TEMPERATURE (DEGREES C)	D(O2)/DT GRAMMOLES/ LITER-MIN.
0.1000E+01	0.7340E-02	0.9832E+00	0.1198E-06	0.3028E+01	0.0	0.0	0.0	0.0	0.5985E-05
0.2000E+01	0.1230E-01	0.9721E+00	0.1097E-06	0.3227E+01	0.0	0.0	0.0	0.0	-.7606E-05
0.3000E+01	0.1230E-01	0.9721E+00	0.9861E-07	0.3326E+01	0.0	0.0	0.0	0.0	-.1467E-04
0.4000E+01	0.1230E-01	0.9721E+00	0.8946E-07	0.3376E+01	0.0	0.0	0.0	0.0	-.1827E-04
0.5000E+01	0.1481E-01	0.9665E+00	0.8115E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2008E-04
0.6000E+01	0.1481E-01	0.9665E+00	0.7362E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2008E-04
0.8000E+01	0.1732E-01	0.9609E+00	0.6059E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2007E-04
0.1000E+02	0.1986E-01	0.9553E+00	0.4987E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2006E-04
0.1200E+02	0.1986E-01	0.9553E+00	0.4104E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2005E-04
0.1400E+02	0.2240E-01	0.9497E+00	0.3378E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2005E-04
0.1600E+02	0.2240E-01	0.9497E+00	0.2780E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2004E-04
0.1800E+02	0.2394E-01	0.9464E+00	0.2288E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2004E-04
0.2000E+02	0.2394E-01	0.9464E+00	0.1883E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2003E-04
0.2400E+02	0.2497E-01	0.9441E+00	0.1275E-07	0.3401E+01	0.0	0.0	0.0	0.0	-.2003E-04
0.2800E+02	0.2497E-01	0.9441E+00	0.8638E-08	0.3401E+01	0.0	0.0	0.0	0.0	-.2003E-04
0.3200E+02	0.2651E-01	0.9408E+00	0.5851E-08	0.3401E+01	0.0	0.0	0.0	0.0	-.2002E-04
0.3600E+02	0.2651E-01	0.9408E+00	0.3963E-08	0.3401E+01	0.0	0.0	0.0	0.0	-.2002E-04
0.4000E+02	0.2651E-01	0.9408E+00	0.2684E-08	0.3401E+01	0.0	0.0	0.0	0.0	-.2002E-04
0.4200E+02	0.2651E-01	0.9408E+00	0.2209E-08	0.3401E+01	0.0	0.0	0.0	0.0	-.2002E-04
0.4400E+02	0.2651E-01	0.9408E+00	0.1818E-08	0.3401E+01	0.0	0.0	0.0	0.0	-.2002E-04

ABSORBANCE
FOR RUN NO. 2 THE COEFICIENT VALUES ARE A=0.2028E-01 B=0.9740E-01 YO=0.6000E-02

PRESSURE IR CELL
FOR RUN NO. 2 THE COEFICIENT VALUES ARE A=0.3832E+00 B=0.4036E+00 YO=0.3034E+01

TEMPERATURE
FOR RUN NO. 2 THE COEFICIENT VALUES ARE A=0.4000E+02 B=0.6000E-01 YO=0.7000E+02

BEST QUADRATIC FIT OF THE TOTAL CO2 LOSS(GRAMS) WITH TIME GIVES COEFS. A=0.0 B=0.0 C=0.0

TABLE 3

RUN NUMBER 3
NO. DATA POINTS 22
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 400.0000
O2 FEED RATE 55.199966 CC/MINUTE
BASELINE TRANSMITTANCE 0.9100

THE DATA ON THIS PAGE WAS REDUCED USING THECALIBRATION RELATIONS DEVELOPED EARLIER IN THIS PROGRAM
FLOW NORMALIZATION FACTOR WAS, 0.97836

THE MEASURED WT. LOSS IS 0.0883 GRAMS THE CO2 LOSS CALCULATED FROM TRANSMITTANCE DATA IS 0.2857 GRAMS

TIME (MINUTES)	ABSORBANCE	TRANSMIT-TANCE	RXN-RATE GRAMMOLES/ LITER-MIN.	IR CELL PRESSURE (TORR)	CO2 MOLE FRACTION	CO2 LOSS GRAMS PER MINUTE	TOTAL CO2 LOSS (GRAMS)	WAFER TEMPERATURE (DEGREES C)	D(O2)/DT GRAMMOLES/ LITER-MIN.
0.1000E+01	0.1456E-01	0.9670E+00	0.1863E-06	0.3078E+01	0.0	0.0	0.0	0.0	0.2896E-06
0.2000E+01	0.1952E-01	0.9560E+00	0.1723E-06	0.3277E+01	0.0	0.0	0.0	0.0	-.1379E-04
0.3000E+01	0.2203E-01	0.9505E+00	0.1595E-06	0.3376E+01	0.0	0.0	0.0	0.0	-.2110E-04
0.4000E+01	0.2454E-01	0.9451E+00	0.1475E-06	0.3425E+01	0.0	0.0	0.0	0.0	-.2482E-04
0.5000E+01	0.2708E-01	0.9396E+00	0.5391E-06	0.3385E+01	0.1793E-02	0.2126E-03	0.2126E-03	0.0	-.2167E-04
0.6000E+01	0.2962E-01	0.9341E+00	0.3155E-05	0.3492E+01	0.1269E-01	0.1599E-02	0.1812E-02	0.0	-.2920E-04
0.7000E+01	0.3218E-01	0.9286E+00	0.5786E-05	0.3499E+01	0.2366E-01	0.2993E-02	0.4805E-02	0.0	-.2911E-04
0.8000E+01	0.3218E-01	0.9286E+00	0.5854E-05	0.3548E+01	0.2333E-01	0.3034E-02	0.7839E-02	0.0	-.3293E-04
0.9000E+01	0.3218E-01	0.9286E+00	0.5769E-05	0.3499E+01	0.2366E-01	0.2993E-02	0.1083E-01	0.0	-.2909E-04
0.1000E+02	0.3476E-01	0.9231E+00	0.8330E-05	0.3463E+01	0.3508E-01	0.4349E-02	0.1518E-01	0.0	-.2577E-04
0.1200E+02	0.3632E-01	0.9198E+00	0.9587E-05	0.3350E+01	0.4324E-01	0.5020E-02	0.2522E-01	0.1148E+03	-.1642E-04
0.1400E+02	0.3632E-01	0.9198E+00	0.9576E-05	0.3350E+01	0.4324E-01	0.5020E-02	0.3526E-01	0.1188E+03	-.1691E-04
0.1600E+02	0.3735E-01	0.9176E+00	0.1058E-04	0.3345E+01	0.4796E-01	0.5554E-02	0.4637E-01	0.1248E+03	-.1634E-04
0.1800E+02	0.4523E-01	0.9011E+00	0.1813E-04	0.3310E+01	0.8417E-01	0.9549E-02	0.6547E-01	0.1288E+03	-.1202E-04
0.2000E+02	0.4523E-01	0.9011E+00	0.1813E-04	0.3310E+01	0.8417E-01	0.9549E-02	0.8457E-01	0.1318E+03	-.1202E-04
0.2200E+02	0.4682E-01	0.8978E+00	0.1962E-04	0.3301E+01	0.9167E-01	0.1034E-01	0.1052E+00	0.1338E+03	-.1094E-04
0.2400E+02	0.4784E-01	0.8956E+00	0.2091E-04	0.3343E+01	0.9527E-01	0.1102E-01	0.1273E+00	0.1348E+03	-.1380E-04
0.2600E+02	0.5056E-01	0.8901E+00	0.2340E-04	0.3324E+01	0.1079E+00	0.1234E-01	0.1520E+00	0.1368E+03	-.1182E-04
0.2800E+02	0.5056E-01	0.8901E+00	0.2340E-04	0.3324E+01	0.1079E+00	0.1234E-01	0.1766E+00	0.1368E+03	-.1181E-04
0.3000E+02	0.5325E-01	0.8846E+00	0.2583E-04	0.3299E+01	0.1210E+00	0.1363E-01	0.2039E+00	0.1408E+03	-.9380E-05
0.3200E+02	0.5325E-01	0.8846E+00	0.2583E-04	0.3299E+01	0.1210E+00	0.1363E-01	0.2312E+00	0.1398E+03	-.9378E-05
0.3600E+02	0.5325E-01	0.8846E+00	0.2587E-04	0.3299E+01	0.1210E+00	0.1363E-01	0.2857E+00	0.1408E+03	-.9374E-05

ABSORBANCE
FOR RUN NO. 3 THE COEFFICIENT VALUES ARE A=0.3876E-01 B=0.7768E-01 YO=0.1500E-01

PRESSURE IR CELL
FOR RUN NO. 3 THE COEFFICIENT VALUES ARE A=0.4198E+00 B=0.2355E+00 YO=0.3084E+01

TEMPERATURE
FOR RUN NO. 3 THE COEFFICIENT VALUES ARE A=0.8072E+02 B=0.7700E-01 YO=0.6700E+02

BEST QUADRATIC FIT OF THE TOTAL CO2 LOSS(GRAMS) WITH TIME GIVES COEFS. A=-.1715E-02 B=-.6205E-03 C=0.2452E-01

TABLE 4

RUN NUMBER 4
NO. DATA POINTS 18
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 600.0000
O2 FEED RATE 55.199966 CC/MINUTE
BASELINE TRANSMITTANCE 0.9250

THE DATA ON THIS PAGE WAS REDUCED USING THECALIBRATION RELATIONS DEVELOPED EARLIER IN THIS PROGRAM
FLOW NORMALIZATION FACTOR WAS, 0.97168

THE MEASURED WT. LOSS IS 0.0999 GRAMS THE CO2 LOSS CALCULATED FROM TRANSMITTANCE DATA IS 0.3232 GRAMS

TIME (MINUTES)	ABSORBANCE	TRANSMIT--TANCE	RXN-RATE GRAMMOLES/ LITER-MIN.	IR CELL PRESSURE (TORR)	CO2 MOLE FRACTION	CO2 LOSS GRAMS PER MINUTE	TOTAL CO2 LOSS (GRAMS)	WAFER TEMPERATURE (DEGREES C)	D(O2)/DT GRAMMOLES/ LITER-MIN.
0.1000E+01	0.1920E-01	0.9568E+00	0.3198E-06	0.3078E+01	0.0	0.0	0.0	0.0	-.5517E-06
0.2000E+01	0.2662E-01	0.9405E+00	0.2847E-06	0.3376E+01	0.0	0.0	0.0	0.0	-.2208E-04
0.3000E+01	0.2913E-01	0.9351E+00	0.2782E-05	0.3481E+01	0.1059E-01	0.1335E-02	0.1335E-02	0.0	-.2949E-04
0.4000E+01	0.3418E-01	0.9243E+00	0.8013E-05	0.3507E+01	0.3213E-01	0.4112E-02	0.5447E-02	0.0	-.3032E-04
0.5000E+01	0.3672E-01	0.9189E+00	0.1032E-04	0.3398E+01	0.4442E-01	0.5341E-02	0.1079E-01	0.0	-.2135E-04
0.6000E+01	0.3929E-01	0.9135E+00	0.1283E-04	0.3387E+01	0.5592E-01	0.6682E-02	0.1747E-01	0.1148E+03	-.1994E-04
0.7000E+01	0.4186E-01	0.9081E+00	0.1535E-04	0.3376E+01	0.6757E-01	0.8023E-02	0.2549E-01	0.1218E+03	-.1853E-04
0.8000E+01	0.4342E-01	0.9049E+00	0.1686E-04	0.3370E+01	0.7461E-01	0.8827E-02	0.3432E-01	0.1288E+03	-.1770E-04
0.9000E+01	0.4446E-01	0.9027E+00	0.1811E-04	0.3415E+01	0.7821E-01	0.9495E-02	0.4381E-01	0.1328E+03	-.2076E-04
0.1000E+02	0.5233E-01	0.8865E+00	0.2600E-04	0.3407E+01	0.1131E+00	0.1367E-01	0.5748E-01	0.1348E+03	-.1836E-04
0.1200E+02	0.5498E-01	0.8811E+00	0.2886E-04	0.3431E+01	0.1239E+00	0.1519E-01	0.8786E-01	0.1476E+03	-.1954E-04
0.1400E+02	0.5766E-01	0.8757E+00	0.3090E-04	0.3358E+01	0.1385E+00	0.1628E-01	0.1204E+00	0.1557E+03	-.1353E-04
0.1600E+02	0.5766E-01	0.8757E+00	0.3133E-04	0.3408E+01	0.1365E+00	0.1651E-01	0.1534E+00	0.1597E+03	-.1716E-04
0.1800E+02	0.5766E-01	0.8757E+00	0.3176E-04	0.3458E+01	0.1346E+00	0.1674E-01	0.1869E+00	0.1637E+03	-.2084E-04
0.2000E+02	0.5766E-01	0.8757E+00	0.3175E-04	0.3458E+01	0.1346E+00	0.1674E-01	0.2204E+00	0.1687E+03	-.2083E-04
0.2200E+02	0.5766E-01	0.8757E+00	0.3218E-04	0.3507E+01	0.1327E+00	0.1698E-01	0.2544E+00	0.1727E+03	-.2456E-04
0.2400E+02	0.5766E-01	0.8757E+00	0.3261E-04	0.3557E+01	0.1308E+00	0.1721E-01	0.2888E+00	0.1757E+03	-.2834E-04
0.2600E+02	0.5766E-01	0.8757E+00	0.3261E-04	0.3557E+01	0.1308E+00	0.1721E-01	0.3232E+00	0.1777E+03	-.2834E-04

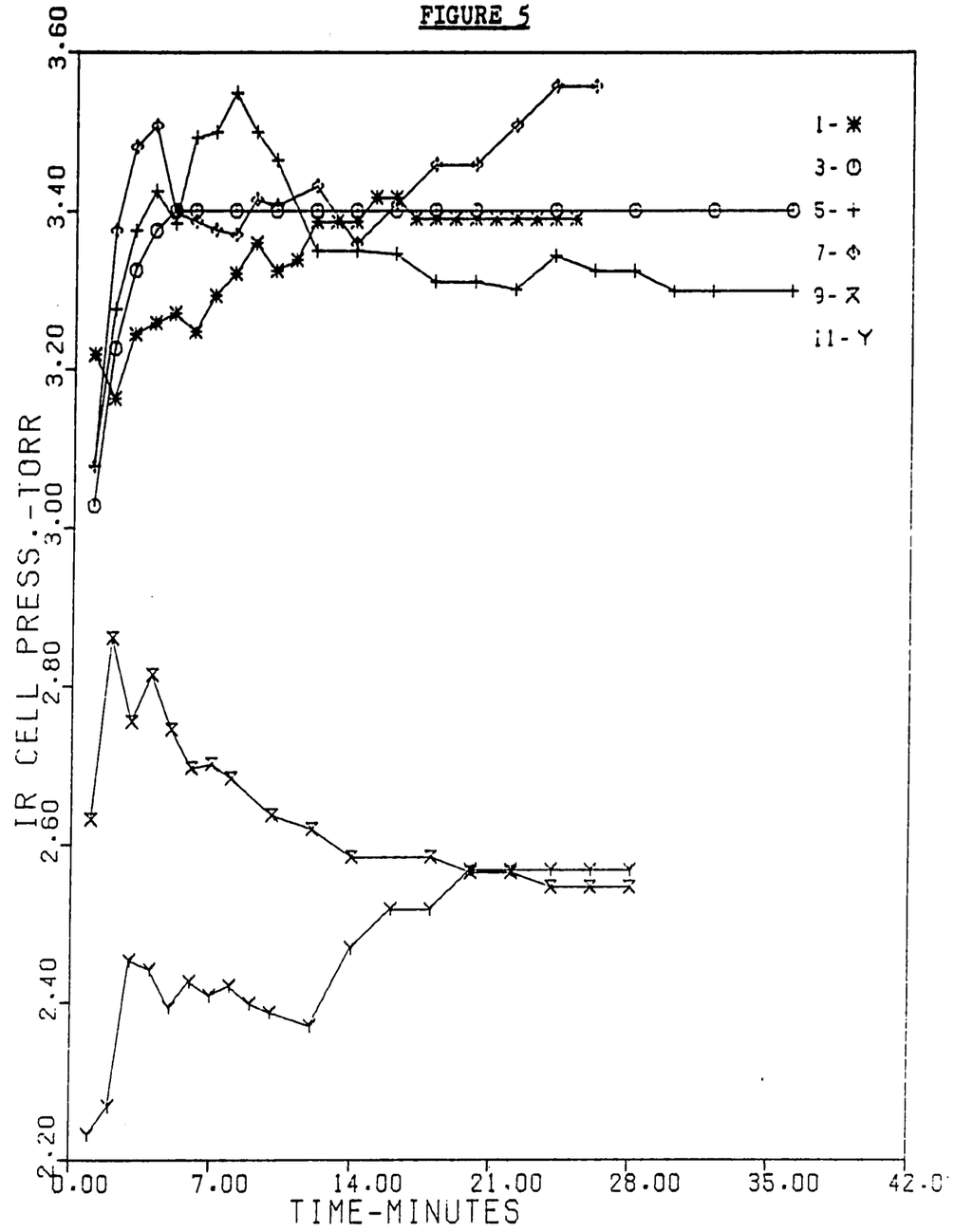
ABSORBANCE
FOR RUN NO. 4 THE COEFICIENT VALUES ARE A=0.4624E-01 B=0.1162E+00 YO=0.1539E-01

PRESSURE IR CELL
FOR RUN NO. 4 THE COEFICIENT VALUES ARE A=0.7059E+00 B=0.1285E+00 YO=0.3084E+01

TEMPERATURE
FOR RUN NO. 4 THE COEFICIENT VALUES ARE A=0.1307E+03 B=0.7069E-01 YO=0.7059E+02

BEST QUADRATIC FIT OF THE TOTAL CO2 LOSS(GRAMS) WITH TIME GIVES COEFS. A=-.1145E-01 B=0.3730E-02 C=0.3711E-03

FIGURE 5



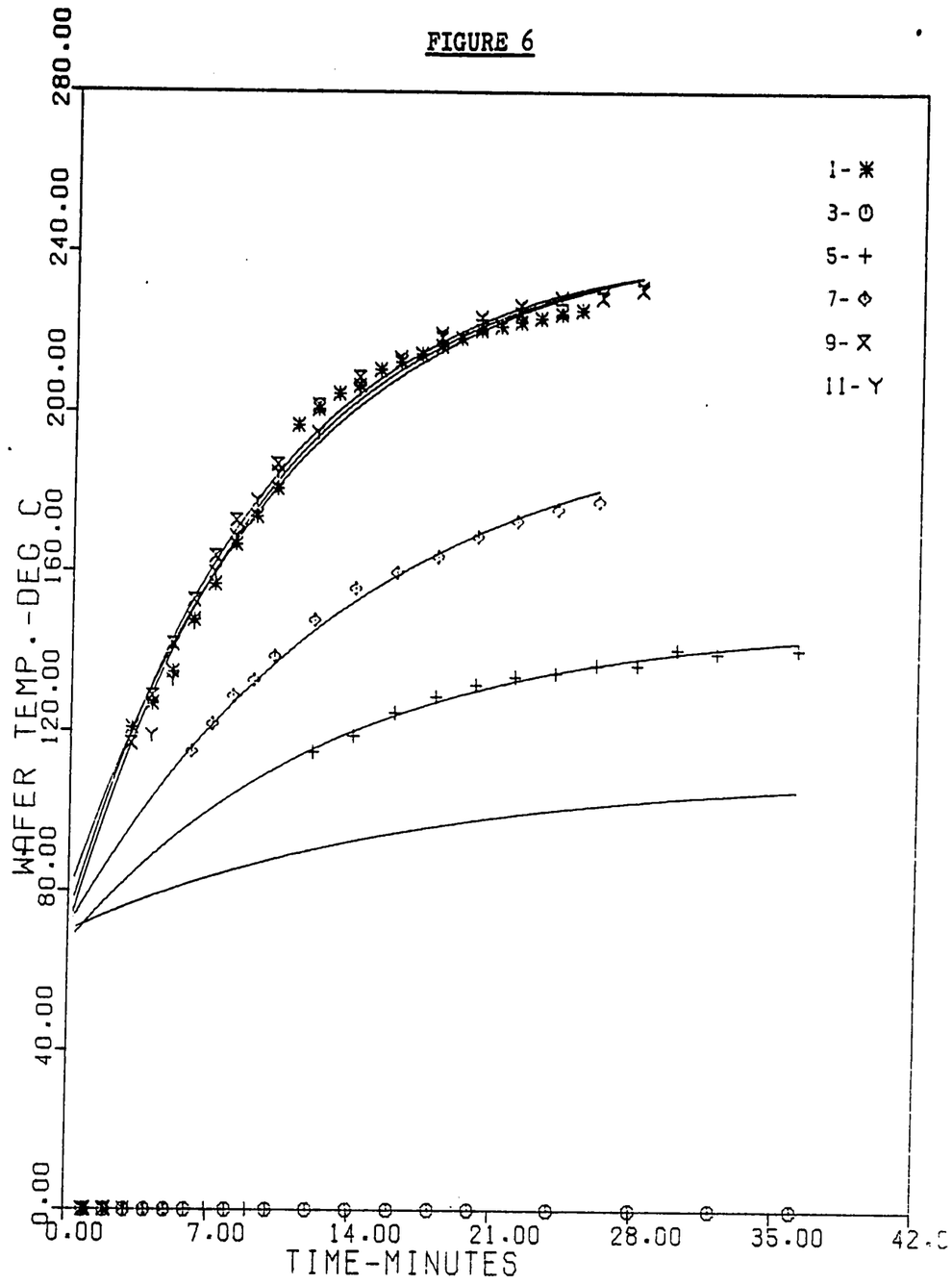
THE SYMBOL NUMBERS ON THE GRAPH CORRESPOND TO RUN NUMBERS AS FOLLOWS:
SYMBOL1-RUN1.SYM.3-RUN2.SYM.5-RUN3.SYM.7-RUN4.SYM.9-RUN5.SYM.11-RUN9

RUN1-800WATTS.RUN2-200WATTS.RUN3-400WATTS.RUN4-600WATTS---02 55 CC/MIN

RUN5-600WATTS.RUN9-800WATTS-----02 28-30 FEED RATE

DATE 04/25/77 16:32:24

FIGURE 6

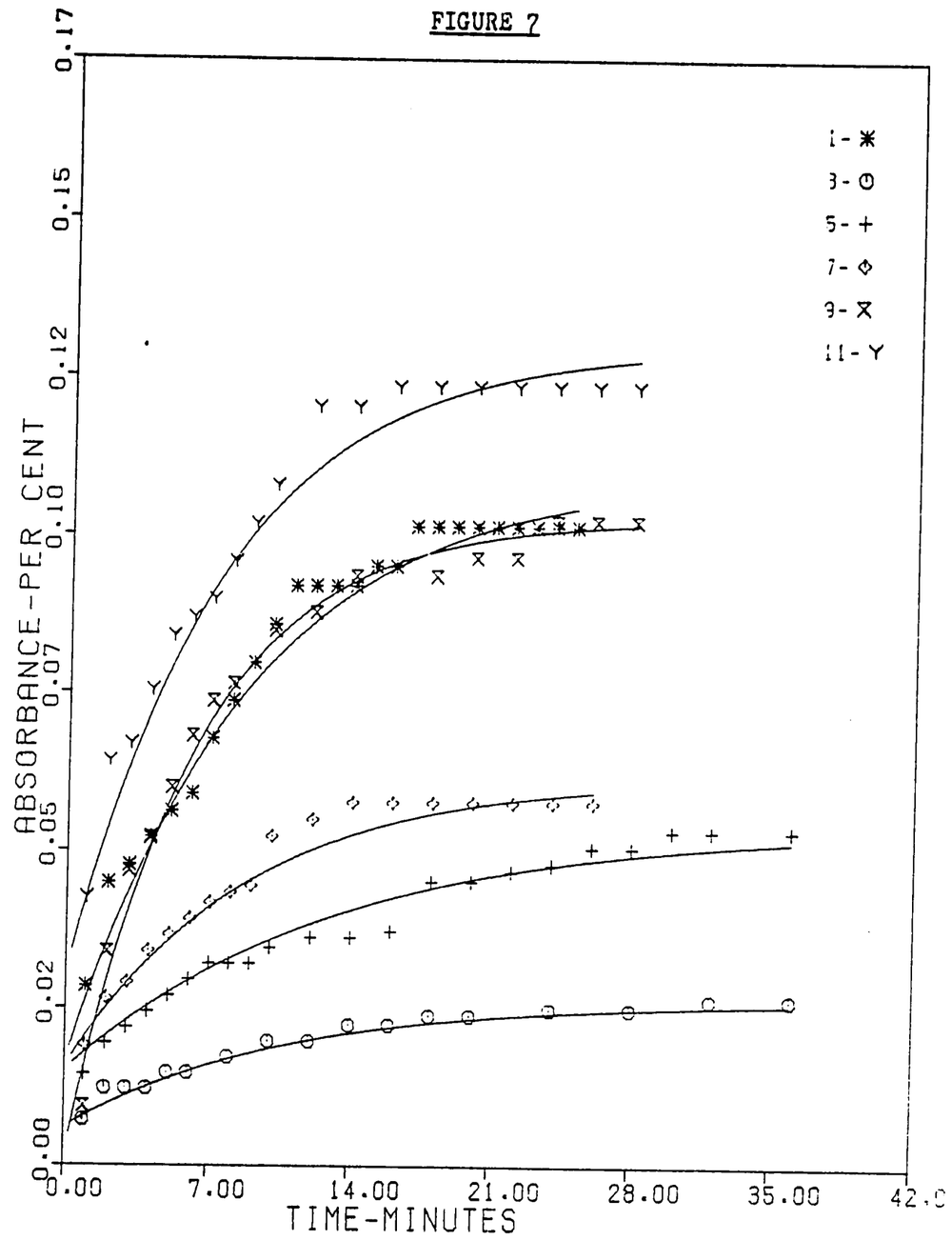


THE SYMBOL NUMBERS ON THE GRAPH CORRESPOND TO RUN NUMBERS AS FOLLOWS:
SYMBOL1-RUN1.SYM.3-RUN2.SYM.5-RUN3.SYM.7-RUN4.SYM.9-RUN5.SYM.11-RUN9

THE LINE WITH NO DATA IS ESTIMATED CURVE (RUN2). TEMP. RUN2 <100.0
WAFER TEMPERATURE WAS MEASURED WITH AN IR PYROMETER.
TEMP. DATA BELOW 100 DEG C IS CALCULATED FROM A FIT OF DATA ABOVE 100 DEG C TO
Y=A*(1-EXP(-B*TIME)) + YO . WHERE A,B,YO ARE CONSTANTS

DATE 04/25/77 16:32:26

FIGURE 7

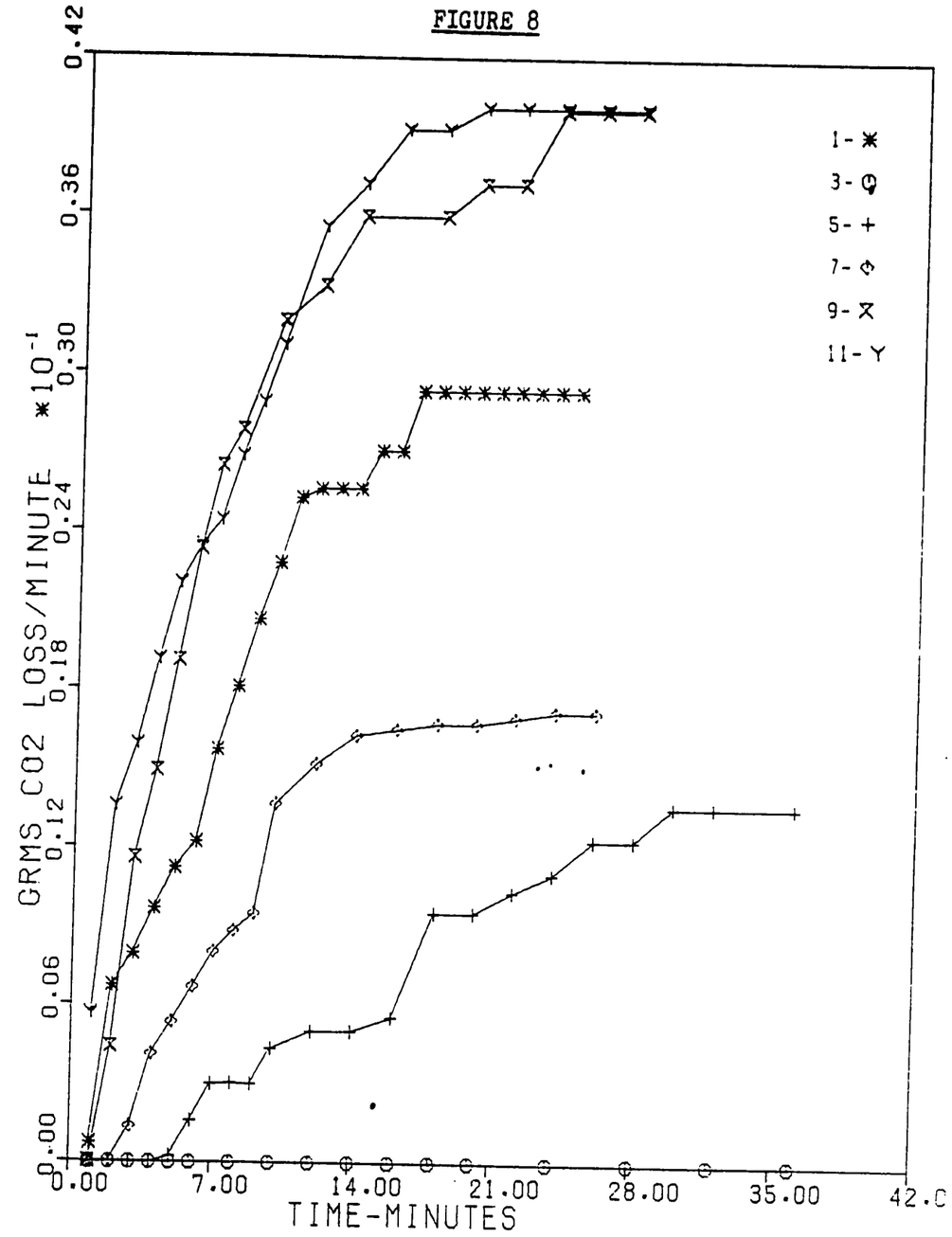


THE SYMBOL NUMBERS ON THE GRAPH CORRESPOND TO RUN NUMBERS AS FOLLOWS:

SYMBOL1-RUN1.SYM.3-RUN2.SYM.5-RUN3.SYM.7-RUN4.SYM.9-RUN5.SYM.11-RUN9
THE LINES ON THIS PLOT WRE CALCULATED FROM A RELATIONSHIP OF THE FORM
Y=A*(1-EXP(-B*TIME)) - YO . WHERE A.B.YO ARE CONSTANTS

DATE 04/28/77 18:51:47

FIGURE 8

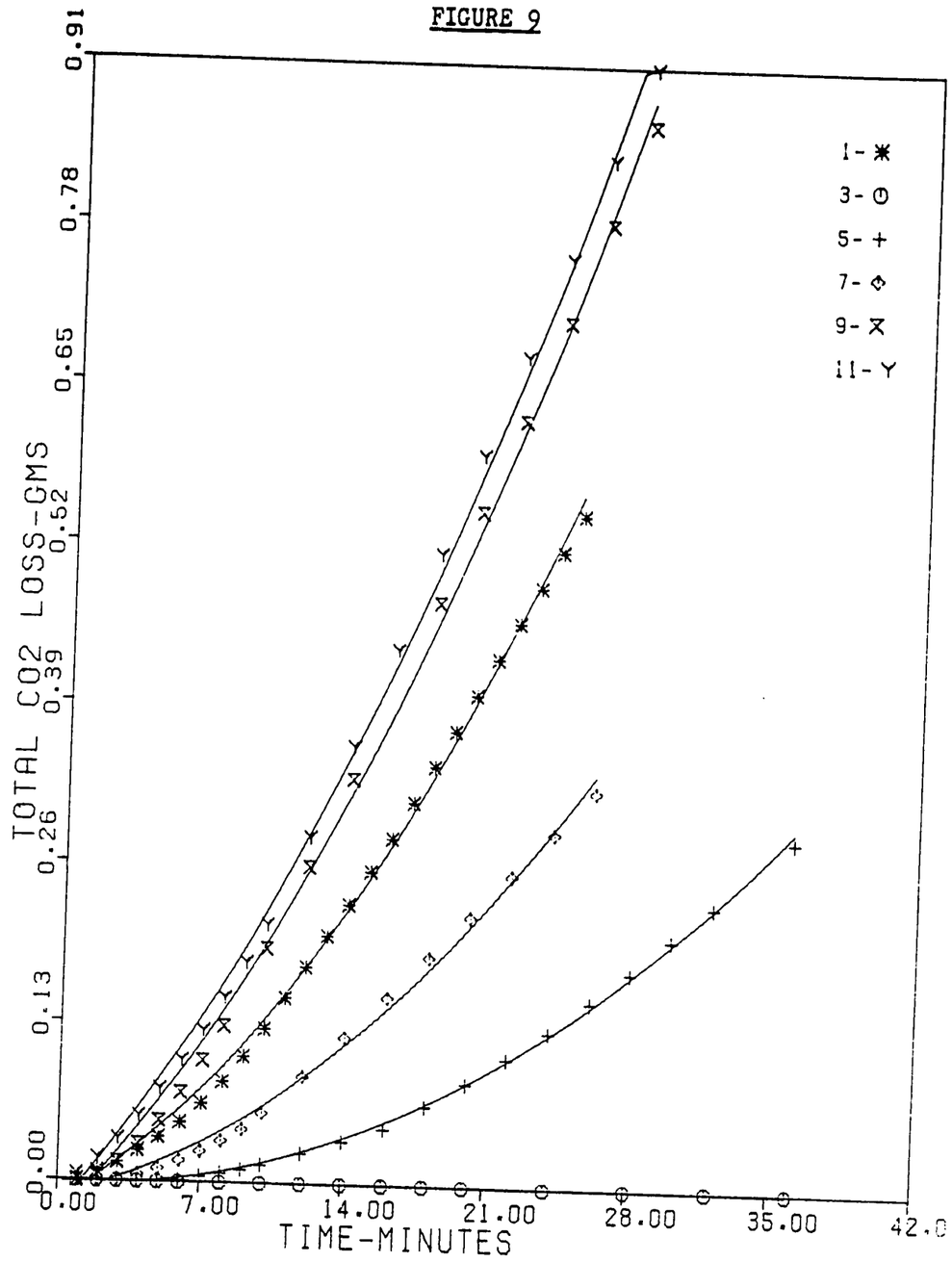


THE SYMBOL NUMBERS ON THE GRAPH CORRESPOND TO RUN NUMBERS AS FOLLOWS:

SYMBOL1-RUN1.SYM.3-RUN2.SYM.5-RUN3.SYM.7-RUN4.SYM.9-RUN5.SYM.11-RUN9

DATE 04/25/77 16:32:31

FIGURE 9



THE SYMBOL NUMBERS ON THE GRAPH CORRESPOND TO RUN NUMBERS AS FOLLOWS:

SYMBOL1-RUN1.SYM.3-RUN2.SYM.5-RUN3.SYM.7-RUN4.SYM.9-RUN5.SYM.11-RUN6
THE LINES ON THIS PLOT WERE CALCULATED FROM THE RELATIONSHIP Y=A+B*X+C*X**2
WHERE A.B. AND C ARE CONSTANTS

DATE 04/25/77 16:32:34

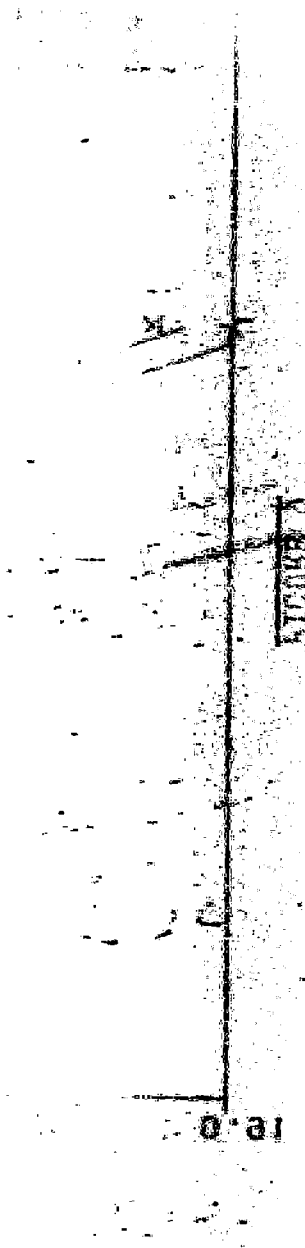


TABLE 10

RUN NUMBER 5
NO. DATA POINTS 17
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 800.0000
O2 FEED RATE 30.359970 CC/MINUTE
BASELINE TRANSMITTANCE 0.9300

THE DATA ON THIS PAGE WAS REDUCED USING THECALIBRATION RELATIONS DEVELOPED EARLIER IN THIS PROGRAM
FLOW NORMALIZATION FACTOR WAS, 0.72761

THE MEASURED WT. LOSS IS 0.2668 GRAMS THE CO2 LOSS CALCULATED FROM TRANSMITTANCE DATA IS 0.8632 GRAMS

TIME (MINUTES)	ABSORBANCE	TRANSMIT--TANCE	RXN-RATE GRAMMOLES/ LITER-MIN.	IR CELL PRESSURE (TORR)	CO2 MOLE FRACTION	CO2 LOSS GRAMS PER MINUTE	TOTAL CO2 LOSS (GRAMS)	WAFER TEMPERATURE (DEGREES C)	D(O2)/DT GRAMMOLES/ LITER-MIN.
0.1000E+01	0.9442E-02	0.9785E+00	0.9711E-06	0.2632E+01	0.0	0.0	0.0	0.0	-.4646E-04
0.2000E+01	0.3398E-01	0.9247E+00	0.9111E-05	0.2861E+01	0.3839E-01	0.4377E-02	0.4377E-02	0.0	-.6376E-04
0.3000E+01	0.4680E-01	0.8978E+00	0.2264E-04	0.2755E+01	0.1097E+00	0.1159E-01	0.1597E-01	0.1168E+03	-.5142E-04
0.4000E+01	0.5203E-01	0.8871E+00	0.2886E-04	0.2814E+01	0.1353E+00	0.1493E-01	0.3089E-01	0.1288E+03	-.5497E-04
0.5000E+01	0.6000E-01	0.8710E+00	0.3671E-04	0.2745E+01	0.1823E+00	0.1912E-01	0.5001E-01	0.1418E+03	-.4714E-04
0.6000E+01	0.6812E-01	0.8548E+00	0.4463E-04	0.2696E+01	0.2308E+00	0.2334E-01	0.7335E-01	0.1527E+03	-.4117E-04
0.7000E+01	0.7361E-01	0.8441E+00	0.5053E-04	0.2701E+01	0.2609E+00	0.2649E-01	0.9984E-01	0.1637E+03	-.4019E-04
0.8000E+01	0.7639E-01	0.8387E+00	0.5306E-04	0.2683E+01	0.2783E+00	0.2786E-01	0.1277E+00	0.1727E+03	-.3802E-04
0.1000E+02	0.8482E-01	0.8226E+00	0.6081E-04	0.2637E+01	0.3312E+00	0.3199E-01	0.1917E+00	0.1866E+03	-.3233E-04
0.1200E+02	0.8767E-01	0.8172E+00	0.6327E-04	0.2619E+01	0.3498E+00	0.3332E-01	0.2583E+00	0.2016E+03	-.3026E-04
0.1400E+02	0.9342E-01	0.8065E+00	0.6820E-04	0.2584E+01	0.3879E+00	0.3595E-01	0.3302E+00	0.2086E+03	-.2626E-04
0.1800E+02	0.9342E-01	0.8065E+00	0.6815E-04	0.2584E+01	0.3879E+00	0.3595E-01	0.4740E+00	0.2186E+03	-.2621E-04
0.2000E+02	0.9633E-01	0.8011E+00	0.7053E-04	0.2564E+01	0.4079E+00	0.3722E-01	0.5485E+00	0.2215E+03	-.2409E-04
0.2200E+02	0.9633E-01	0.8011E+00	0.7052E-04	0.2564E+01	0.4079E+00	0.3722E-01	0.6229E+00	0.2245E+03	-.2408E-04
0.2400E+02	0.1022E+00	0.7903E+00	0.7586E-04	0.2546E+01	0.4454E+00	0.4004E-01	0.7030E+00	0.2255E+03	-.2138E-04
0.2600E+02	0.1022E+00	0.7903E+00	0.7586E-04	0.2546E+01	0.4454E+00	0.4004E-01	0.7831E+00	0.2285E+03	-.2137E-04
0.2800E+02	0.1022E+00	0.7903E+00	0.7585E-04	0.2546E+01	0.4454E+00	0.4004E-01	0.8632E+00	0.2305E+03	-.2137E-04

ABSORBANCE
FOR RUN NO. 5 THE COEFICIENT VALUES ARE A=0.1025E+00 B=0.1675E+00 Y0=0.0000E-02

PRESSURE IR CELL
FOR RUN NO. 5 THE COEFICIENT VALUES ARE A=0.4048E+00 B=0.3414E+00 Y0=0.2637E+01

TEMPERATURE
FOR RUN NO. 5 THE COEFICIENT VALUES ARE A=0.1695E+03 B=0.1071E+00 Y0=0.7268E+02

BEST QUADRATIC FIT OF THE TOTAL CO2 LOSS(GRAMS) WITH TIME GIVES COEFS. A=-.3251E-01 B=0.1720E-01 C=0.5533E-03

TABLE 11

RUN NUMBER 9
NO. DATA POINTS 19
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 800.0000
02 FEED RATE 27.599976 CC/MINUTE
BASELINE TRANSMITTANCE 0.9100

THE DATA ON THIS PAGE WAS REDUCED USING THECALIBRATION RELATIONS DEVELOPED EARLIER IN THIS PROGRAM
FLOW NORMALIZATION FACTOR WAS, 0.93794

THE MEASURED WT. LOSS IS 0.2829 GRAMS THE CO2 LOSS CALCULATED FROM TRANSMITTANCE DATA IS 0.9153 GRAMS

TIME (MINUTES)	ABSORBANCE	TRANSMIT-TANCE	RXN-RATE GRAMMOLES/ LITER-MIN.	IR CELL PRESSURE (TORR)	CO2 MOLE FRACTION	CO2 LOSS GRAMS PER MINUTE	TOTAL CO2 LOSS (GRAMS)	WAFER TEMPERATURE (DEGREES C)	D(O2)/DT GRAMMOLES/ LITER-MIN.
0.1000E+01	0.4259E-01	0.9066E+00	0.1152E-04	0.2232E+01	0.1071E+00	0.5661E-02	0.5661E-02	0.0	-.2053E-05
0.2000E+01	0.6417E-01	0.8626E+00	0.2642E-04	0.2268E+01	0.2483E+00	0.1359E-01	0.1925E-01	0.0	-.5394E-06
0.3000E+01	0.6695E-01	0.8571E+00	0.3075E-04	0.2453E+01	0.2466E+00	0.1592E-01	0.3516E-01	0.0	-.1015E-04
0.4000E+01	0.7538E-01	0.8407E+00	0.3679E-04	0.2441E+01	0.2996E+00	0.1915E-01	0.5431E-01	0.1188E+03	-.7982E-05
0.5000E+01	0.8398E-01	0.8242E+00	0.4221E-04	0.2393E+01	0.3596E+00	0.2204E-01	0.7635E-01	0.1328E+03	-.3819E-05
0.6000E+01	0.8689E-01	0.8187E+00	0.4492E-04	0.2426E+01	0.3728E+00	0.2351E-01	0.9986E-01	0.1468E+03	-.5058E-05
0.7000E+01	0.8981E-01	0.8132E+00	0.4665E-04	0.2408E+01	0.3938E+00	0.2445E-01	0.1243E+00	0.1597E+03	-.3550E-05
0.8000E+01	0.9572E-01	0.8022E+00	0.5123E-04	0.2420E+01	0.4284E+00	0.2689E-01	0.1512E+00	0.1687E+03	-.3191E-05
0.9000E+01	0.1017E+00	0.7912E+00	0.5505E-04	0.2398E+01	0.4699E+00	0.2892E-01	0.1801E+00	0.1777E+03	-.4519E-05
0.1000E+02	0.1078E+00	0.7802E+00	0.5914E-04	0.2387E+01	0.5104E+00	0.3111E-01	0.2112E+00	0.1846E+03	0.6800E-06
0.1200E+02	0.1202E+00	0.7582E+00	0.6757E-04	0.2370E+01	0.5927E+00	0.3558E-01	0.2824E+00	0.1946E+03	-.6976E-06
0.1400E+02	0.1202E+00	0.7582E+00	0.7061E-04	0.2469E+01	0.5689E+00	0.3721E-01	0.3568E+00	0.2056E+03	-.3145E-05
0.1600E+02	0.1234E+00	0.7527E+00	0.7453E-04	0.2518E+01	0.5765E+00	0.3930E-01	0.4354E+00	0.2136E+03	-.6299E-05
0.1800E+02	0.1234E+00	0.7527E+00	0.7451E-04	0.2518E+01	0.5765E+00	0.3930E-01	0.5140E+00	0.2196E+03	-.6279E-05
0.2000E+02	0.1234E+00	0.7527E+00	0.7605E-04	0.2568E+01	0.5654E+00	0.4012E-01	0.5943E+00	0.2235E+03	-.7520E-05
0.2200E+02	0.1234E+00	0.7527E+00	0.7604E-04	0.2568E+01	0.5654E+00	0.4012E-01	0.6745E+00	0.2265E+03	-.7508E-05
0.2400E+02	0.1234E+00	0.7527E+00	0.7603E-04	0.2568E+01	0.5654E+00	0.4012E-01	0.7548E+00	0.2285E+03	-.7500E-05
0.2600E+02	0.1234E+00	0.7527E+00	0.7602E-04	0.2568E+01	0.5654E+00	0.4012E-01	0.8350E+00	0.2295E+03	-.7493E-05
0.2800E+02	0.1234E+00	0.7527E+00	0.7601E-04	0.2568E+01	0.5654E+00	0.4012E-01	0.9153E+00	0.2315E+03	-.7488E-05

ABSORBANCE
FOR RUN NO. 9 THE COEFICIENT VALUES ARE A=0.9977E-01 B=0.1363E+00 YO=0.3080E-01

PRESSURE IR CELL
FOR RUN NO. 9 THE COEFICIENT VALUES ARE A=0.8064E+00 B=0.1364E+00 YO=0.2334E+01

TEMPERATURE
FOR RUN NO. 9 THE COEFICIENT VALUES ARE A=0.1669E+03 B=0.9508E-01 YO=0.7840E+02

BEST QUADRATIC FIT OF THE TOTAL CO2 LOSS(GRAMS) WITH TIME GIVES COEFS. A=-.2465E-01 B=0.1932E-01 C=0.5382E-03

TABLE 12

All of the temperature and pressure data on this table are uncalibrated.

Wt. Loss (grams)	Wt. Loss Rate (grams/min.)	Temperature (Deg. C)	Pressure (torr)	Time (min.)
0.0048	0.0048	---	5.2	1
0.0092	0.0046	---	5.2	2
0.0142	0.0047	---	5.2	3
0.0212	0.0053	109	5.2	4
0.0291	0.0058	120	5.2	5
0.0483	0.0069	148	5.3	7
0.0552	0.0069	162	5.6	8
0.0674	0.0068	180	6.0	10
0.0954	0.0080	190	6.2	12
0.1463	0.0091	205	6.5	16
0.1800	0.0100	210	6.5	18
0.2605	0.0110	216	6.5	24

FIGURE 12a

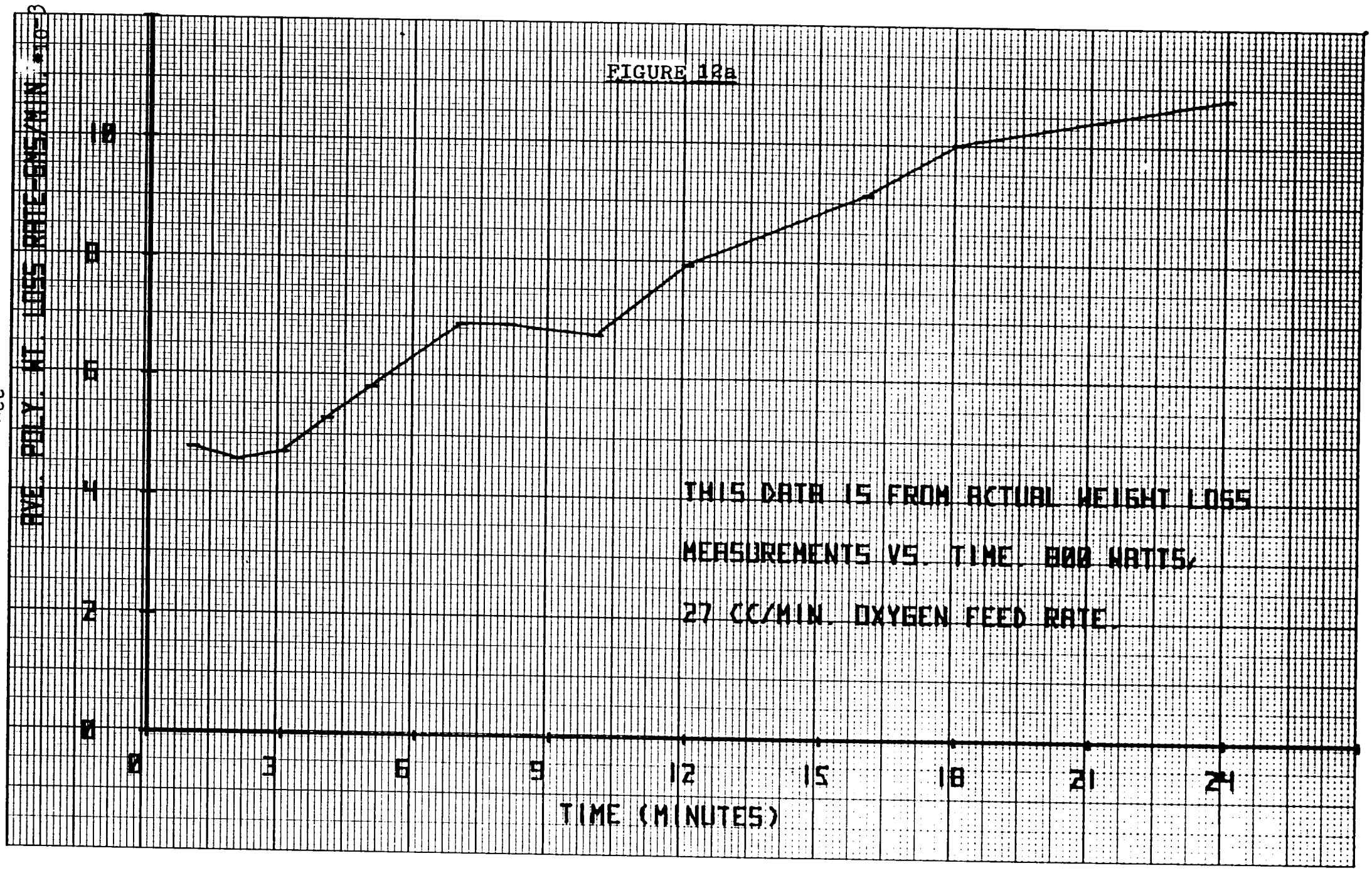


FIGURE 12b

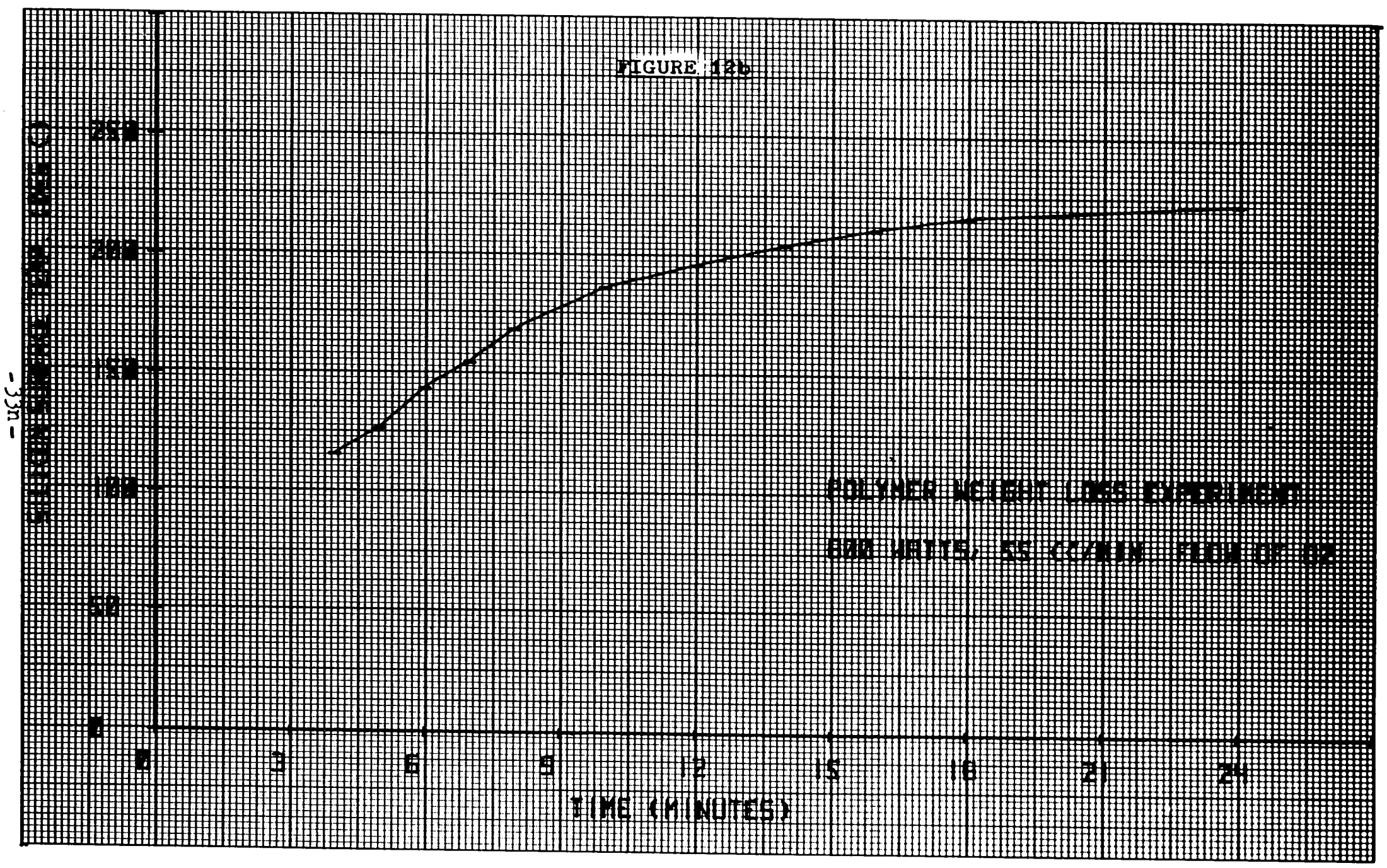


FIGURE 12c

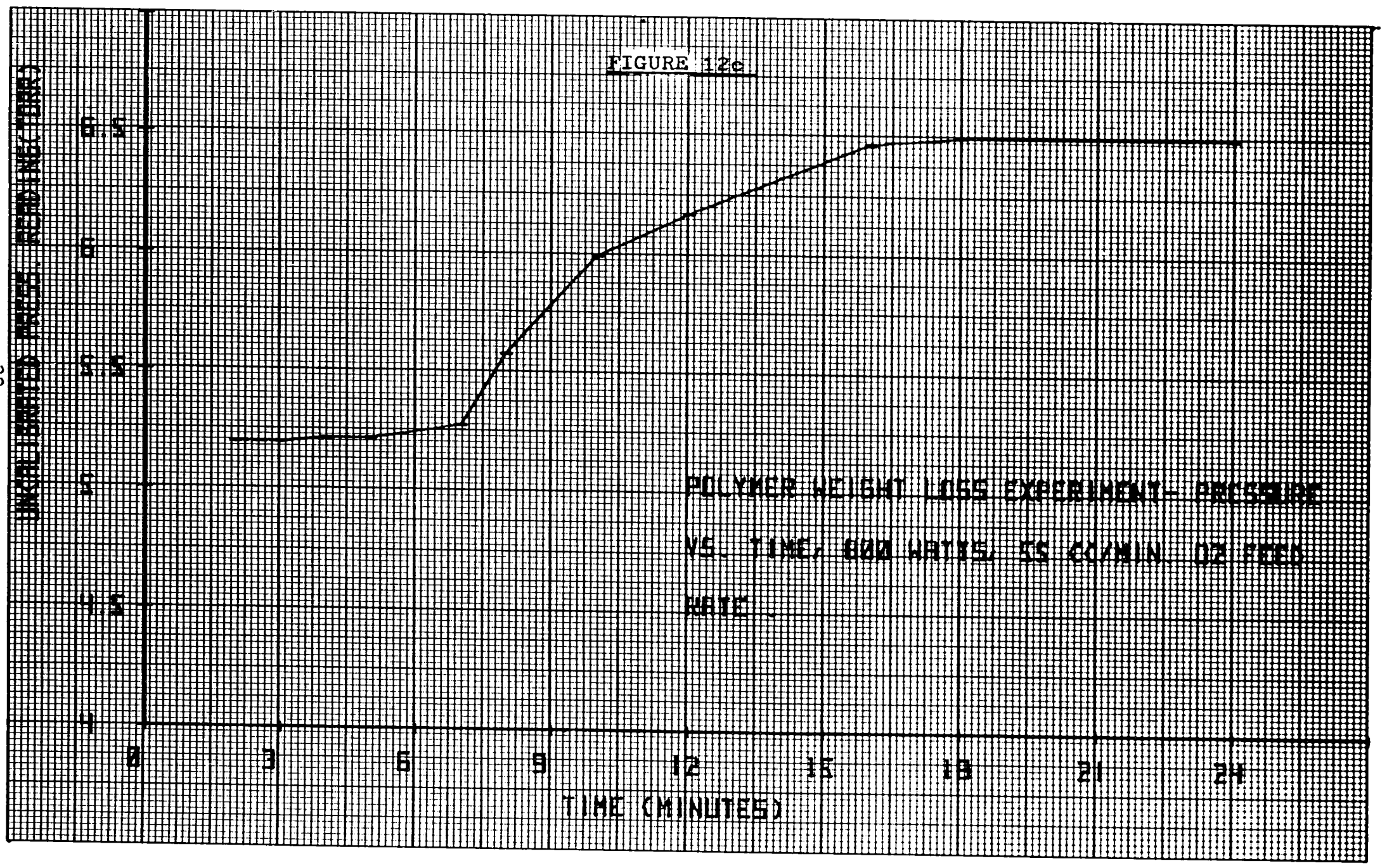


TABLE 13

All of the temperature and pressure data on this table are uncalibrated.

No wafers/chamber		2 wafers/chamber		6 wafers/chamber		10 wafers/chamber		
Temp.(=.5) (Deg. C)	Press. (torr)	Temp.(=.5) (Deg. C)	Press. (torr)	Temp.(=.5) (Deg. C)	Press. (torr)	Temp.(=.5) (Deg. C)	Press. (torr)	Time (min.)
---	6.0	---	5.9	---	5.9	---	6.0	1
---	6.0	---	6.1	---	6.1	---	6.3	2
---	6.0	---	6.3	---	6.2	---	6.5	3
---	6.0	---	6.4	---	6.3	---	6.7	4
---	6.0	110	6.5	108	6.5	110	6.8	5
108	6.0	120	6.6	120	6.6	120	6.9	6
114	6.0	130	6.7	130	6.7+	129	6.9	7
120	6.0	140	6.7	139	6.9	138	7.0	8
126	6.0	---	---	---	---	---	---	9
132	6.0	153	6.8	154	6.9+	150	7.0	10
140	6.0	162	6.9	164	7.0	164	7.1	12
148	5.9	170	6.9	172	7.0	174	7.1	14
154	5.9	175	6.9	177	7.0	180	7.2	16
159	5.9	End= 16.4min.		182	7.0	186	7.2	18
164	5.9			186	7.0	192	7.2	20

Resist Wt. Loss in Grams	=	0.0429	0.1085	0.1421
Ave. Wt. Loss Rate in Grams/minute	=	0.00262	0.00542	0.00710
Wt. Loss Rate/wafer in gms./min.-wafer	=	0.00131	0.00090	0.00071

FIGURE 14

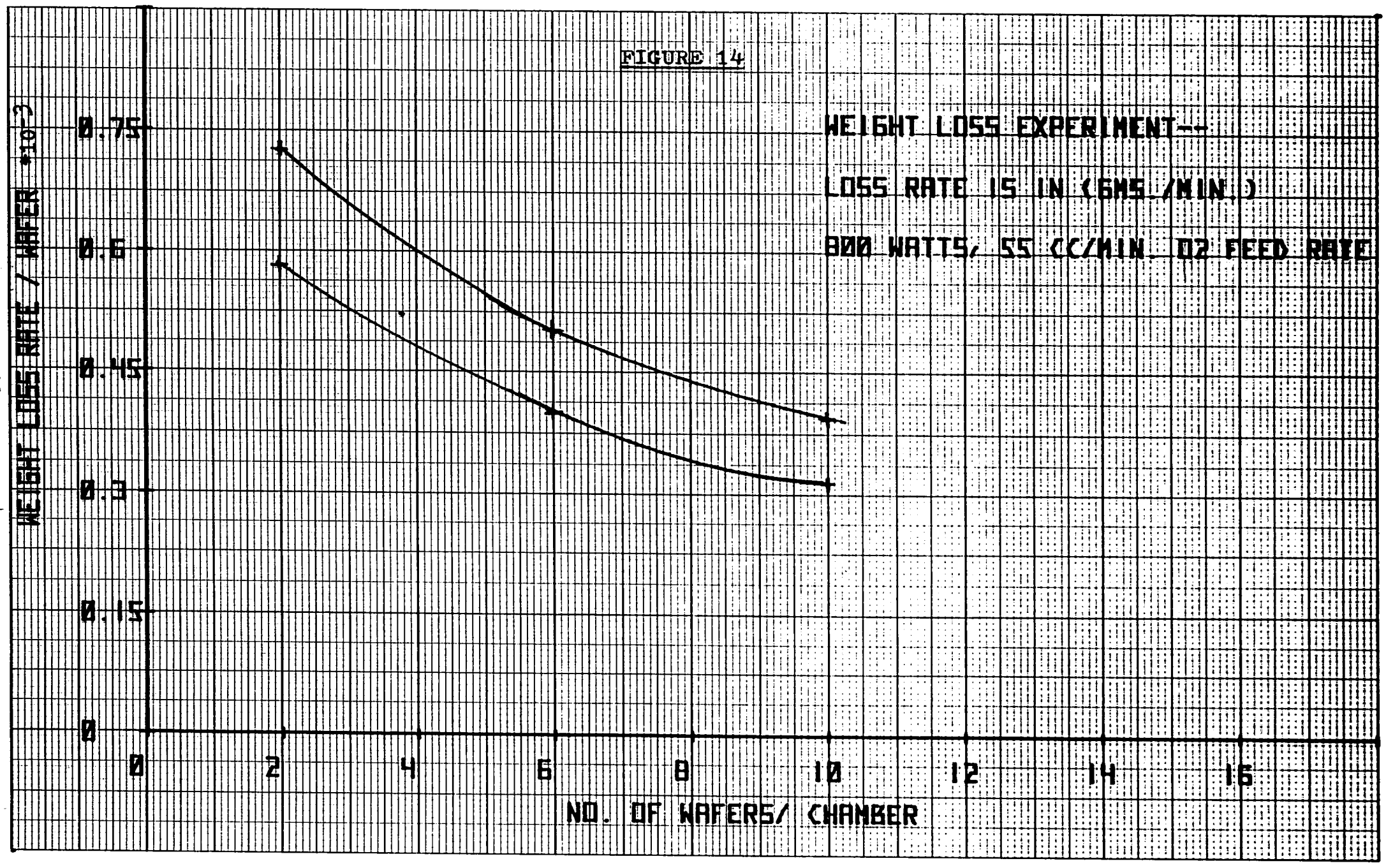


FIGURE 15

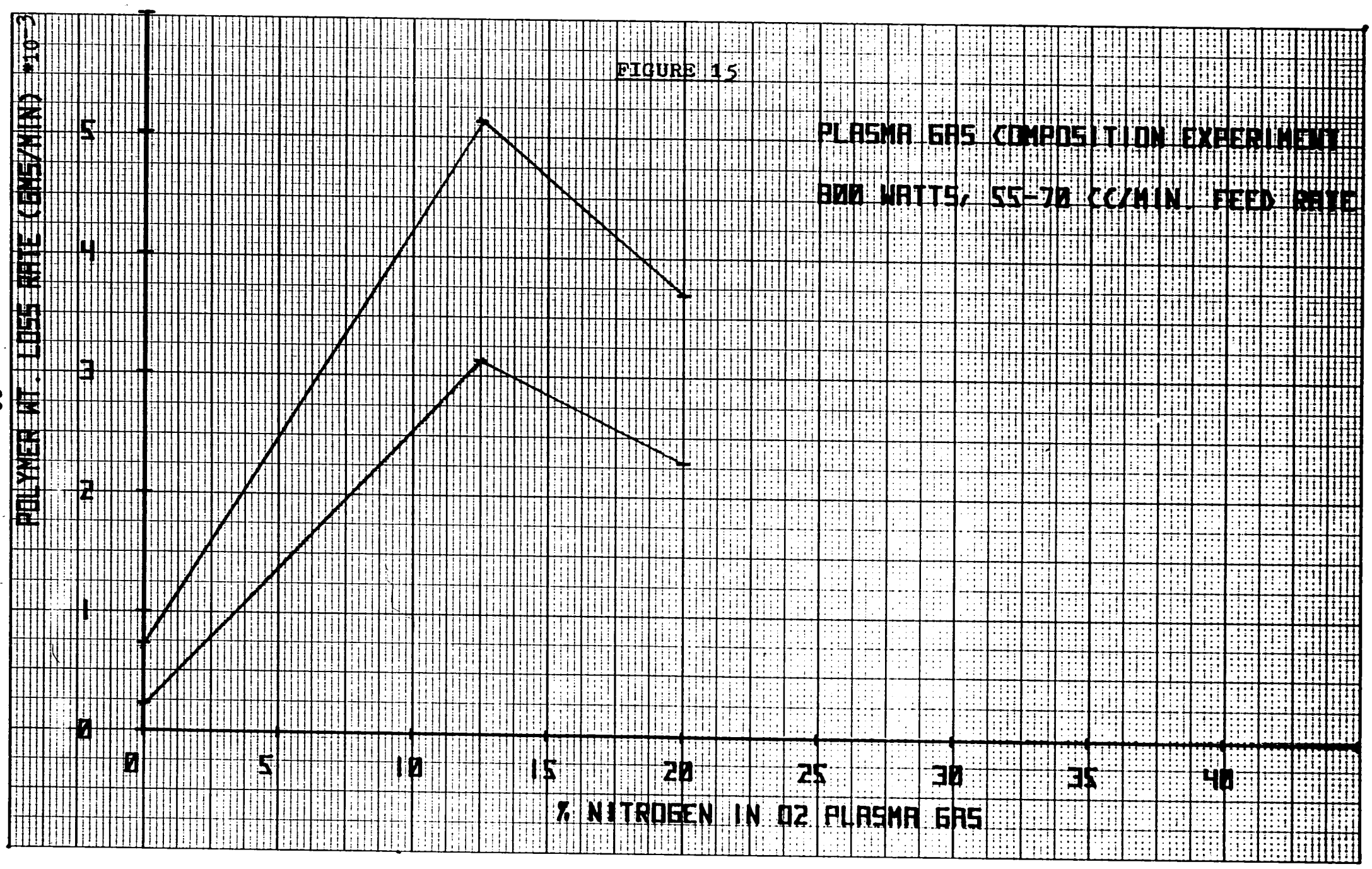


TABLE 16

RUN NUMBER 6
NO. DATA POINTS 10
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 800.0000
O2 FEED RATE 20.000000 CC/MINUTE
BASELINE TRANSMITTANCE 0.9300

TIME (MINUTES)	RELATIVE TRANSMITTANCE	REACTOR PRESSURE METER (TORR)	PYROMETER METER (DEG. CELSIUS)
1.0000	0.8850	5.5000	0.0
2.0000	0.8650	5.8000	0.0
3.0000	0.8500	5.9000	0.0
4.0000	0.8300	5.9000	118.0000
5.0000	0.8000	6.0000	135.0000
6.0000	0.7850	6.1000	145.0000
7.0000	0.7800	6.3000	150.0000
8.0000	0.7600	8.5000	156.0000
10.0000	0.7500	10.0000	170.0000
12.0000	0.7400	10.0000	188.0000

TABLE 17

RUN NUMBER 7
NO. DATA POINTS 8
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 800.0000
O2 FEED RATE 20.000000 CC/MINUTE
BASELINE TRANSMITTANCE 0.9200

TIME (MINUTES)	RELATIVE TRANSMITTANCE	REACTOR PRESSURE METER (TORR)	PYROMETER METER (DEG. CELSIUS)
1.0000	0.8700	5.4000	0.0
2.0000	0.8400	5.6000	0.0
3.0000	0.8400	5.5000	110.0000
4.0000	0.8200	5.5000	125.0000
5.0000	0.8000	5.5000	138.0000
6.0000	0.7900	5.5000	152.0000
7.0000	0.7650	5.6000	162.0000
8.0000	0.7300	5.8000	172.0000

TABLE 18

RUN NUMBER 8
NO. DATA POINTS 11
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 800.0000
02 FEED RATE 20.000000 CC/MINUTE
BASELINE TRANSMITTANCE 0.9100

TIME (MINUTES)	RELATIVE TRANSMITTANCE	REACTOR PRESSURE METER (TORR)	PYROMETER METER (DEG. CELSIUS)
1.0000	0.8350	4.6000	0.0
2.0000	0.8150	4.7500	0.0
3.0000	0.7950	4.9000	110.0000
4.0000	0.7800	5.0000	128.0000
5.0000	0.7750	5.0000	138.0000
6.0000	0.7550	5.1000	154.0000
7.0000	0.7450	5.2000	166.0000
8.0000	0.7350	5.3000	177.0000
9.0000	0.7150	5.6000	184.0000
10.0000	0.7050	5.8000	190.0000
12.0000	0.6850	7.5000	206.0000

DISCUSSION OF RESULTS

The purpose of this research was to determine the effect of several variables on the rate of breakdown of cyclic polyisoprene and novalak resin photoresists in an oxygen plasma. Most of the experiments with negative resist were very successful with a significant addition to the data base on the process of oxygen plasma removal. However, positive resist (novalak resin) was dropped from the project when the experiments could not be adequately controlled to obtain useful information.

Computer Solution

In order to solve the myriad relationships necessary to correlate the data into useful information, it was necessary to construct the computer program which comprises Appendix VI. A two part block diagram is used to describe this program's computations in overview. The first part, Table 19, breaks out the major sections of the calibration and experiment calculations including reference to equations in the text. While the second part, Table 20, details the plotting performed. Since the program is fundamentally algebraic and the method of carrying out the analytical solution is presented in a previous section of this paper (see Theory - Descriptive Equations), only the data and new relationships discovered in data analysis will be discussed.

FIGURE 19

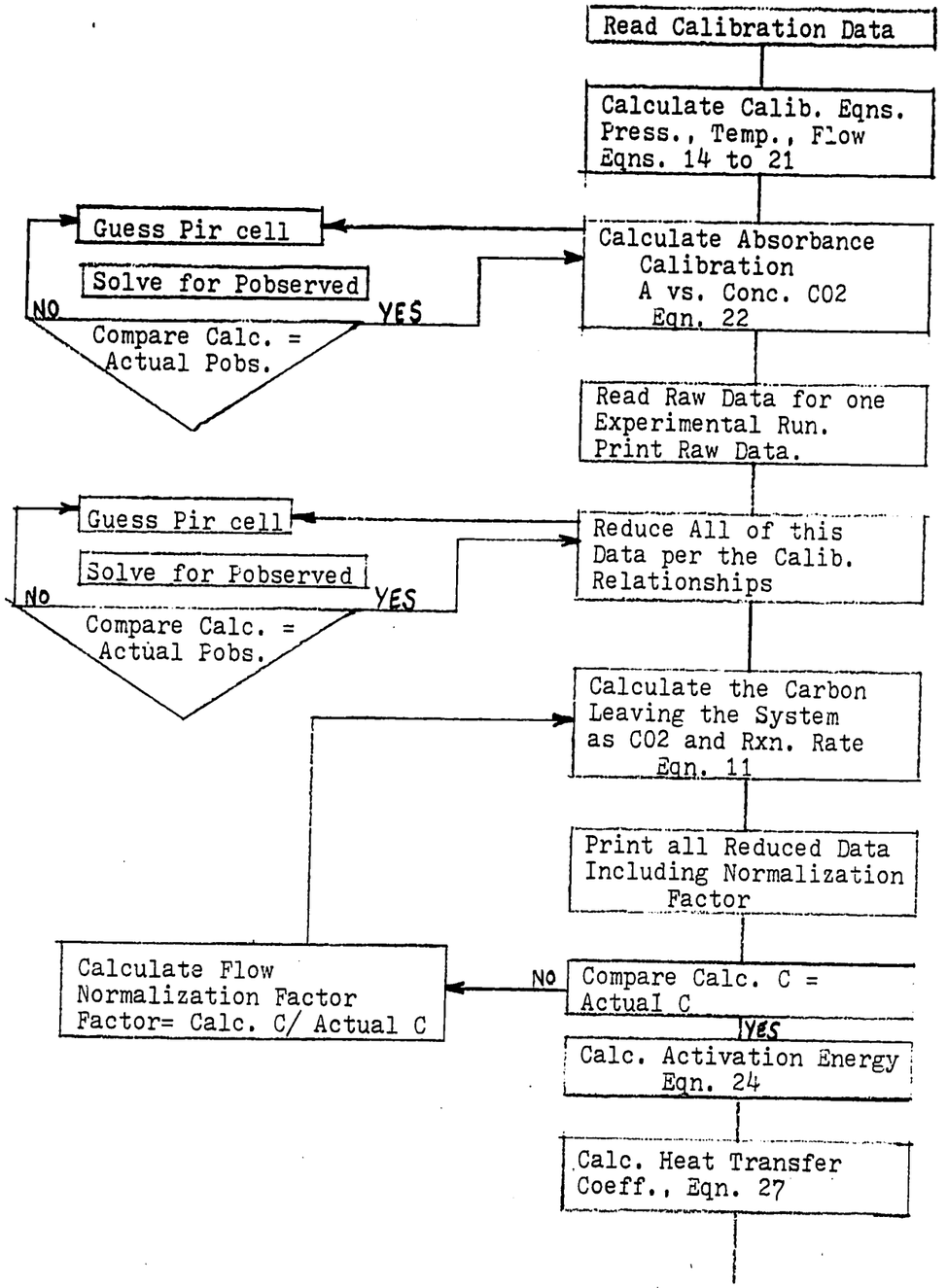
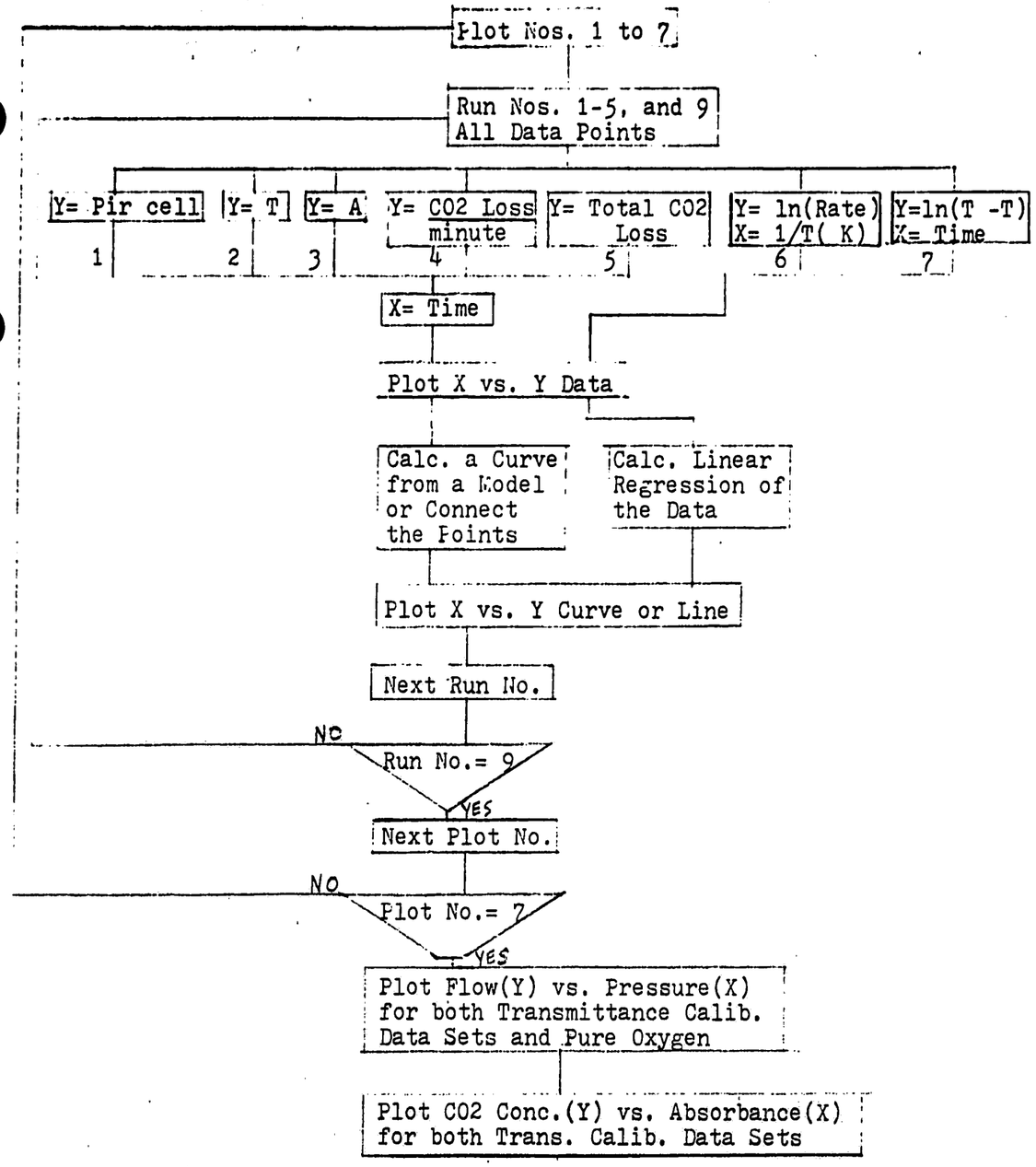

Read Calibration Data
Calculate Calib. Eqns. Press., Temp., Flow Eqns. 14 to 21
Guess Pir cell
Solve for Pobserved
NO
YES
Compare Calc. = Actual Pobs.
Calculate Absorbance Calibration A vs. Conc. CO2 Eqn. 22
Read Raw Data for one Experimental Run. Print Raw Data.
Guess Pir cell
Solve for Pobserved
No
YES
Compare Calc. = Actual Pobs.
Reduce All of this Data per the Calib. Relationships
Calculate the Carbon Leaving the System as CO2 and Rxn. Rate Eqn. 11
Print all Reduced Data Including Normalization Factor
Calculate Flow Normalization Factor Factor= Calc. C/ Actual C
NO
Compare Calc. C = Actual C
YES
Calc. Activation Energy Eqn. 24
Calc. Heat Transfer Coeff., Eqn. 27

FIGURE 20


Plot Nos. 1 to 7
Run Nos. 1-5, and 9
All Data Points
Y= Pir cell
1
Y= T
2
Y= A
3
Y= CO2 Loss minute
4
Y= Total CO2 Loss
5
Y= ln(Rate) X= 1/T(K)
6
Y=ln(T -T) X= Time
7
X= Time
Plot X vs. Y Data
Calc. a Curve from a Model or Connect the Points
Calc. Linear Regression of the Data
Plot X vs. Y Curve or Line
Next Run No.
NO
Run No.= 9
YES
Next Plot No.
NO
Plot No.= 7
YES
Plot Flow(Y) vs. Pressure(X) for both Transmittance Calib. Data Sets and Pure Oxygen
Plot CO2 Conc.(Y) vs. Absorbance(X) for both Trans. Calib. Data Sets

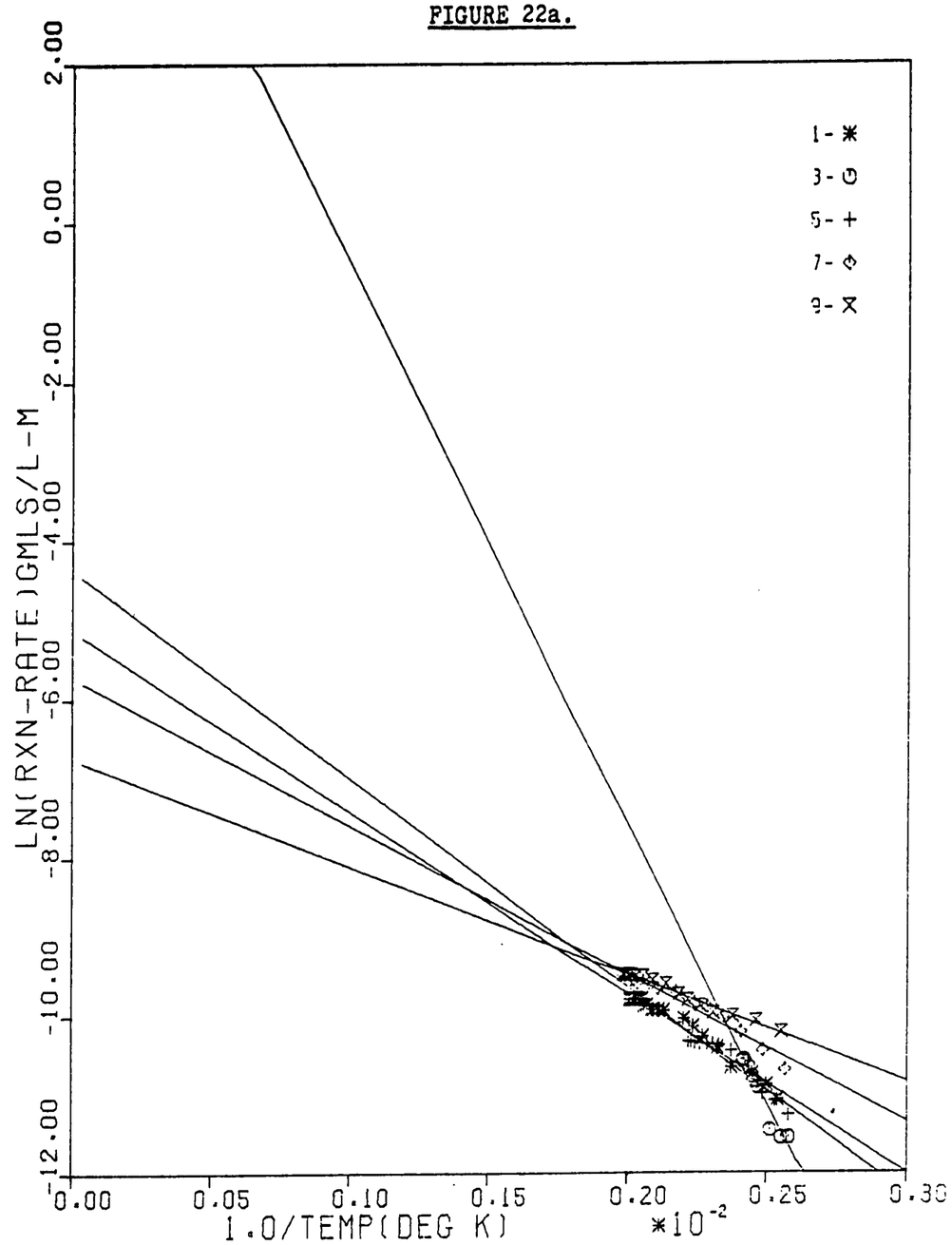
Data Analysis

The major cross check on the reaction rate calculation was the measurement of the weight of carbon removed from the polymer. Since the carbon-hydrogen ratio in polyisoprene is 1:1.6, the molecular weight of a fundamental unit of the polymer is 13.6 grams/ grammole and the carbon removed from the polymer is simply 12/13.6 of the weight of polymer removal. Another value for the carbon leaving the polymer and the system is provided by the carbon dioxide material balance equation where the carbon weight is 12/44 of the total calculated weight of carbon dioxide leaving the system (44 is the molecular wt. of CO2). Ideally these two independently measured values should be identical. Table 21 shows how these carbon values actually compared in this work. The extremely poor match in the values for run 2 at 200 watts was probably because the low transmittance signal being measured was swamped by the size of the experimental error. Therefore, the rate data for 200 watts appear to be invalid and will be excluded from this analysis. The trend of the remainder of the data on Table 21 reveals that the 55 cc/min. flow rate runs 1,3,4 have calculated carbon losses up to 30% above the polymer weight loss value while the 27 cc/min. runs 5,9 have calculated carbon losses up to 30% below the polymer weight loss value. The cause of this deviation is believed to be an inaccuracy in the slope of the flow vs. pressure curve (Fig. AP IV-4) used in the carbon dioxide calculation. If the slope of this line is

TABLE 21

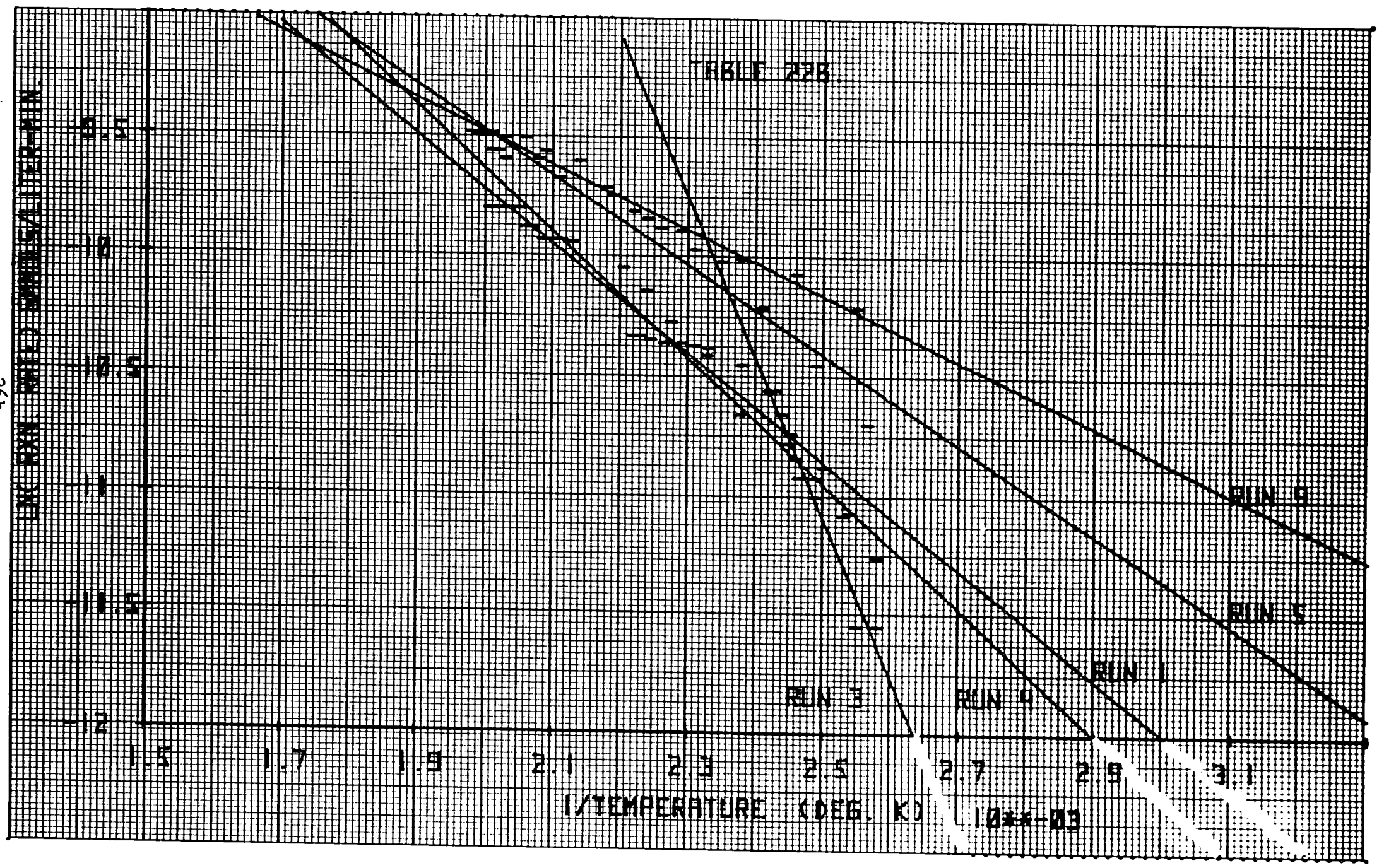
Run No.	Carbon Wt. Loss from the Polymer (grams)	Carbon Loss Calc. from CO2 Conc. (grams)	Normalization Factor Calc./Actual
3	0.0779	0.0762	.978
4	0.0880	0.0856	.972
1	0.149	0.195	1.31
5	0.235	0.171	.728
9	0.250	0.234	.936

FIGURE 22a.



THE SYMBOL NUMBERS ON THE GRAPH CORRESPOND TO RUN NUMBERS AS FOLLOWS:
SYMBOL1-RUN1,SYM.3-RUN3.SYM.5-RUN5.SYM.7-RUN5.SYM.9-RUN9.
THE RXN RATE HAS UNITS OF GMMOLES/LITER-MINUTE

DATE 04/28/77 19:51:55



decreased from 33.3 to approximately 23.2, then the trend in this data would disappear. The only justification for considering such a change is the effect water vapor might have in altering this line. The flow vs. pressure measurements for O2, CO2, and H2O vapor are plotted on Fig. AP IV-6. However, the water vapor data taken to construct this plot are not as reliable as the oxygen and carbon dioxide values due to the ease with which the water vapor could condense in the system even under vacuum conditions. It is doubtful whether a reliable flow-pressure curve could be constructed for this room temperature system. Rather than manipulate the slope of the flow-pressure line, the same result can be achieved by normalizing the calculated exhaust flow rate . This was accomplished by dividing each flow rate by the ratio of the total calculated carbon loss to the measured carbon weight loss. For example, since the carbon loss ratio for run no. 1 was 1.31, all of the exhaust flow rates calculated were divided by 1.31. With the exhaust flow rates and consequently the reaction rates normalized , it became possible to plot the reaction rate data vs. $1/T(^{\circ}K)$ in order to determine the temperature dependence of the rate. This plot of runs 1, 3, 4, 5, and 9 is Fig. 22a and b. Since the plot shows the data to be linear, the rate controlling step in the polymer breakdown must either be zero order or the concentration must be constant to satisfy equation (2),

$$\text{Rate} = A * \exp(-E_{act}/R * T) * f(C) \qquad (2)$$

If $f(C) = (C)^n$ as proposed by D'Allelio and Parker [36], then only when n=0 and $f(C) = (C)^0 = 1.0$ or when C= a constant and $f(C) = (C)^n = J$, a different constant, will eqn. (2) yield a linear temperature dependence for the reaction rate. Since the rate in eqn. (2) is dC/dt, a generalized integration of this eqn. can be carried out with the substitution of the constant J for f(C) as follows,

$$dC/dt = A * \exp(-E_{act}/R * T) * J$$

$$C = J*A * \exp(-E_{act}/R * T) * t$$

$$\ln(\Delta C/\Delta t) = \ln(J*A * \exp(-E_{act}/R * T))$$

$$\ln(\text{Rate}) = -E_{act}/R * T + \ln(J*A) \qquad (24)$$

The meaning of the concentration independent reaction rate equation is that none of the chemical reactions, eqns.(2-10) are rate controlling in the polymer degradation process. Therefore, a thermophysical limit (i.e. diffusion, heat flux, or phase change) must be controlling the rate of the decomposition.

When thermal or physical processes are rate controlling in polymer degradation, the process is termed ablation. Ablation of polymers was studied extensively by researchers working on the space program in the 1960's [35,37]. These studies were directed toward finding materials which could

dissipate the maximum thermal load per pound on re-entry of a space vehicle. They discovered that the process of ablation consisted of; energy transfer to the polymer surface, rupture of the polymer bonds at the surface and/or in the bulk, melting and charring or sublimation of the surface layer, diffusion with possible reaction across a boundary layer into the gas phase, and possibly further reaction in the gas phase. In the present experiments although reaction is undoubtedly occurring in both the boundary layer and the bulk gas phase to form CO2 and H2O, these steps are not rate limiting as the rate-temperature data demonstrated.

In order to understand this physical process, the activation energy, Eact, and the frequency factor, A, are calculated for the various experiments. These values are easily obtained from Fig. 22a and b.

TABLE 23

Run #	Power (watts)	Flow (cc/min.)	Eact (cal./ gmmol)	A (gmmols/ min.)	Regression Fit (± 1.0=perfect fit)
3	400	55	14000	690.0	-.97
4	600	55	5200	0.0128	-.95
1	800	55	4550	0.0059	-.99
5	800	30	3700	0.0033	-.98
9	800	27	2700	0.0012	-.99

From this chart it is readily apparent that chain rupture at the polymer surface cannot be rate controlling since the activation energies are far too low, 2-6 Kcal./gmmole. Chain rupture for cyclic polyisoprene would have energies of 80-120 Kcal./gmmole [38].

Although the 400 watt data give anomalous appearing values of Eact and A, the remainder of the data are in good agreement. The values are clustered by flow rate. At 27 cc/min. Eact averages 3200 + 500 cal./gmmole while A averages 0.0022 + 0.0010 gmmoles/min.. The higher flow, 55 cc/min., yields values of Eact of 4900 + 400 cal./gmmole and A 0.0094 + 0.0040 gmmoles/liter-min.. Since the values for the 600 and 800 watt runs are so close, it is assumed that no change in the degradation process occurs in this power region. However, the 400 watt data indicate that a significant change in the degradation process occurrs at the lower power levels.

The lower activation energy and frequency factor for the low flow condition (low pressure) increases the rate of polymer decomposition at a fixed temperature by approximately 28%. For example, at 200 C, Vr*R(55 cc/min.) = 0.00069 while Vr*R(27 cc/min.) = 0.00088 gmmoles/min. Since it should be possible to explain this rate increase in terms of the degradation process, those ablation processes having activation energies of the magnitude 1-10 Kcal./gmmole will be explored. These processes are energy transfer to the

polymer surface, sublimation of the surface layer (charring was not observed in the polyisoprene experiments and melting is not favored under vacuum conditions), or diffusion into the bulk gas phase. Although the diffusion process cannot be eliminated rigorously from consideration, under vacuum conditions the resistance to diffusion must be extremely small due to the large mean free path of the chain fragments (e.g. an isoprene unit has a free path of 1-10 microns at 3 torr). In addition, a gaseous diffusion dependent rate would have a temperature dependence in a 3/2 power of temperature not a logarithmic relationship. Therefore, the possible rate controlling processes are energy transfer and sublimation of the surface fragments. However, if gas phase thermal transfer were limiting, then the rate would have a 1/2 power dependence on temperature. This energy transfer process even if not rate limitting is extremely important for the understanding of the plasma reactor. Therefore, it will be examined before proceeding with determination of the sublimation energies of the surface fragments.

Heat Transfer

Heat transfer to the polymer surface for bond rupture and sublimation is accomplished by ion and electron bombardment. From the data on temperature increase with time, the heat transfer to the surface can be determined. The temperature rise was found to follow the equation for transient heating with negligible internal resistance to conduction

compared to the resistance of the surface convection [39]. This eqn. was previously mentioned under the section, PROCEDURE. In more detail, it is,

$$(T_\infty - T)/(T_\infty - T_o) = \exp(- N*t) \qquad (23)$$

where $N = (Ar*h/\rho*CP*V)_{Si}$ = a constant with the dimension of 1/time

h= the surface heat transfer coefficient, cal./cm^2-min.-$^\circ$C

Ar / V = the area to volume ratio of the wafers, 100 cm^{-1}

CP= the heat capacity of the silicon, 0.168 cal./gm.-$^\circ$C

ρ = the density of silicon, 2.33 grams/cm^3

Using these values for the constants in the definition of N gives the simple relationship, h= N/k1= N/ 51.09 (cm^2 $^\circ$C/cal.), where k1 is a constant. These eqns. can be used to define for a specific power level, the actual thermal energy input to the wafer as well as the wafer time-temperature history, a result which allows extrapolation of the low power runs to low times where pyrometer data were not obtained. Taking the natural loqarithm of both sides of eqn. (23) gives,

$$\ln(T_\infty - T) = -N * t + \ln(T_\infty - T_o) \qquad (27)$$

Thus plotting the wafer temperature(T) vs. time (t) experimental data as $\ln(T_\infty - T)$ vs. t for various values of T_∞ should yield one value of T_∞ which makes the plot linear.

Although this problem is in fact a two parameter search, i.e. h and T_{∞}, it was found that a straight line fit was very sensitive to T_{∞} for a small range of values of T . If further consideration is given to this phenomenon a logical reason for this effect might quickly become apparent. From the linear plot obtained, the slope of the line will be N whose value will determine the heat transfer coefficient , h, from eqn. (27). The intercept of this line then determines the value of the initial temperature, T_o, seen by the wafers as opposed to room temperature from which they actually started. Using this information, the thermal energy flux from ion bombardment at any time is now,

$$q = h * Ar * (T_{\infty} - T) \qquad (28)$$

And in order to obtain the total energy flux from zero to any time, t, it is only necessary to integrate eqn. (28) with time,

$$Q = \int_0^t q * dt = \int_0^t h * Ar * (T_{\infty} - T) * dt \qquad (29)$$

where by rearranging eqn. (23) for the value of T,

$$T = f(t) = T_{\infty} - (T_{\infty} - T_o) * \exp(- N * t) \qquad (30)$$

and combining eqns. (29) and (30) yields,

$$Q = \int_0^t h * Ar * (T_{\infty} - T_o) * \exp(- N * t) * dt \qquad (31)$$

Substituting N = k1 * h into eqn. (31) and multiplying by -k1/-k1 puts eqn. (31) into the analytically integral form exp(-u) * du,

$$Q = Ar*(T_\infty - T_o)* \int_o^t \exp(-k1*h*t) * -k1/-k1 * dt \quad (32)$$

$$Q = Ar/k1 * (T_o - T_\infty) * \exp(-k1 * h *(t - 0)) \quad (33)$$

$$Q = Ar/k1 * (T_\infty - T_o) * (1.0 - \exp(-k1 * h * t) \quad (34)$$

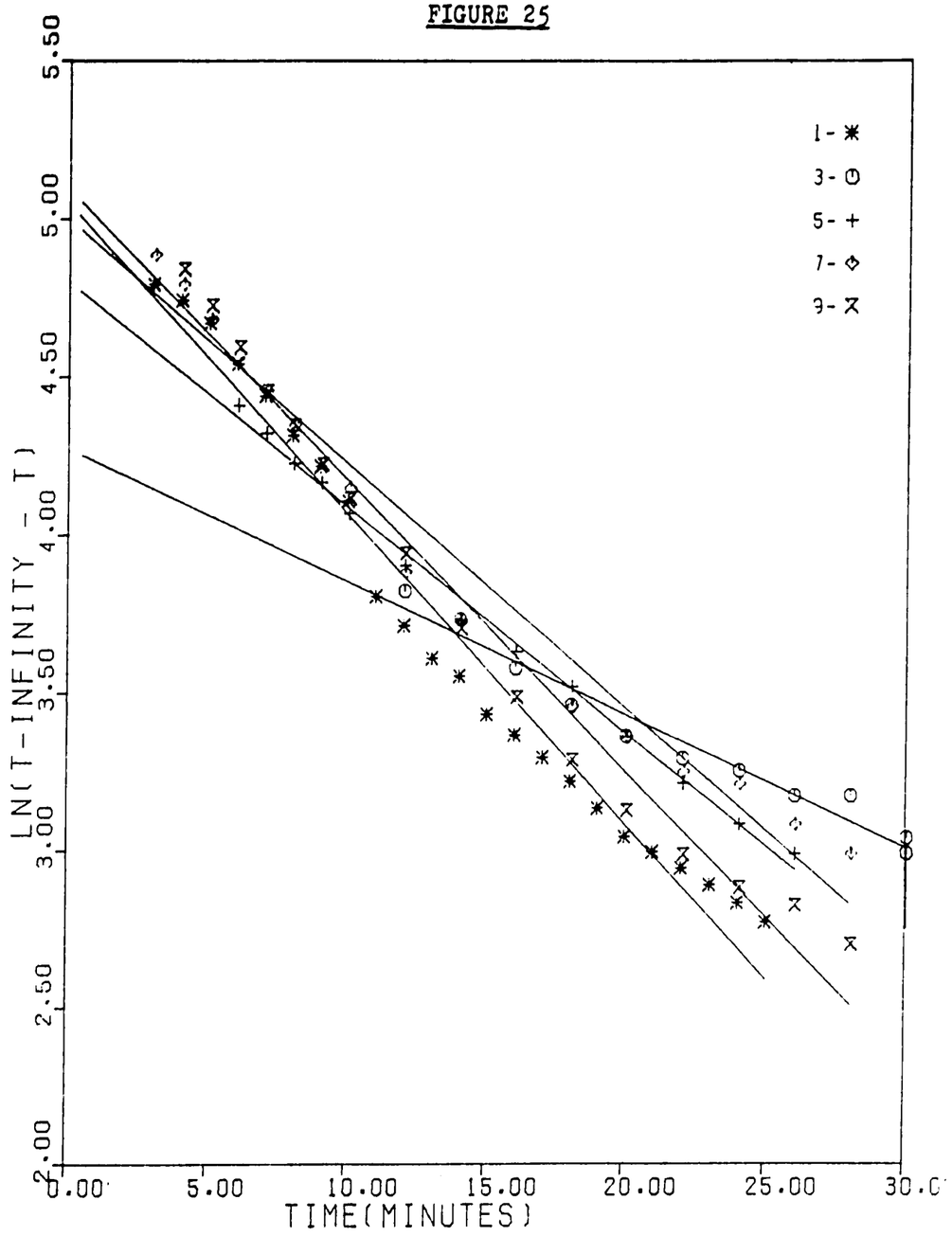
This equation with the constant values determined from the linear fit to eqn. (27) provides the description of the thermal flux to the polymer surface for any time or power level. The computer calculations carried out to analyze the rate data also included a section to determine all of the constants needed in eqn. (34) for each run. These constants are listed below on Table 24, and the plot from which they were obtained is Figure 25.

TABLE 24

Run #	T (Deg. C)	T (Deg. C)	N (1/min.)	h (cal./cm^2-min.$^\circ$C)	Regression Fit ($\pm$1=perfect)
3	161	97	0.0358	0.0007	0.96
4	198	76	0.0715	0.0014	0.96
1	242	86	0.0976	0.0019	0.99
5	251	102	0.0766	0.0015	0.98
9	247	84	0.0920	0.0018	0.99

Although the heat transfer coefficient is constant at the two flow rates , 27 and 55 cc/min., it does increase slightly (25%) with an increase in power from 400-800 watts. Constancy of this heat transfer coefficient with flow rate compared with the significant change in reaction rate with

FIGURE 25



THE SYMBOL NUMBERS ON THE GRAPH CORRESPOND TO RUN NUMBERS AS FOLLOWS=:
SYMBOL1-RUN1.SYM.3-RUN3.SYM.5-RUN5.SYM.7-RUN7.SYM.9-RUN9

THE Y-AXIS IS THE NAT. LOG OF THE BULK PLASMA GAS TEMP. - THE SILICON WAFER TEMPERATURE. T-INFINITY IS THE GAS TEMPERATURE.

DATE 04/25/77 16:32:37

flow rate removes the possibility that heat transfer is the rate controlling process in photoresist decomposition.

Fragment Evaporation

Only surface fragment evaporation remains as an unexplored ablation process which might account for all of the data gathered on photoresist decomposition. The energy of evaporation of a long polymer chain cannot of course be determined since the energy to rupture the chain of the molecule is lower than its evaporation energy. However, the units in which this study is interested are the small surface fragments of the polymer. It is the resistance of these fragments to evaporation which are believed to be the rate limiting step to this process. An estimate of the evaporation energy of a monomer unit of a polymer may be obtained based on the monomer's solubility parameter, [40].

$$\delta = (\text{Evap.} / \text{Vl})^{1/2} \qquad (25)$$

$$\text{Evap.} = \delta^2 * \text{Vl} = \delta^2 * \text{Mw} / \rho \qquad (26)$$

where Evap.= energy of vaporization, cal./gmmole

δ = solubility parameter, $(\text{cal.}/\text{cm}^3)^{1/2}$

Vl= molar volume of the monomer, cm^3/ gmmole

Mw= molecular weight of the monomer, grams/gmmole

ρ = density of the monomer, grams/cm^3

For isoprene δ has a value of 7.4, Mw is 68 gms./gmmole, and ρ is 0.68 gms./cm^3 . Therefore, the vaporization energy is 5.5 Kcal./gmmole which is the same order of magnitude as

the activation energy measured for the rate limiting degradation process. This evaporation energy analysis ought to be done with data on cyclic polyisoprene or the cyclic isoprene monomer. However, this data is not readily available.

CONCLUSIONS

The rate of breakdown of cyclic polyisoprene photoresist has been determined for a range of temperatures between 100-220 ^{o}C , two oxygen gas feed rates, three compositions of the feed gas, and three power levels. Calculations based on these data indicate a linear increase in the heat transfer coefficient to the silicon substrate with increasing power, h= 0.0007 - 0.0019 cal./cm^{2} -min.- ^{o}C, while this coefficient is nearly constant versus oxygen feed rate (i.e. pressure). On the other hand, the activation energy for the polymer degradation process appears to be essentially constant versus power in the 600-800 watt rf power region. However, activation energy undergoes a significant decrease as oxygen feed rate (i.e. pressure) decreases indicating that the rate limiting step for the polymer decomposition is evaporation of chain fragments from the polymer surface. Further confirmation of this conclusion is provided by calculation of the theoretical evaporation energy for the polymer (i.e. isoprene monomer fragments). This polymer evaporation energy is calculated as 5.5 Kcal./gmmole. while the measured activation energy for the degradation process is 2.5-5.5 Kcal./gmmole. A large increase in the activation energy of the process to 14 Kcal./gmmole. was observed at lower rf power levels (400 watts). This increase indicates that a change in the nature of the degradation process oc-

curs in low power oxygen plasmas. This data base on oxygen plasma decomposition of cyclic polyisoprene will be examined even more extensively in the future for further conclusions.

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APPENDIX I

Calibration of the Thermocouple Pressure Gauges

When the experiments were performed, careful readings were taken from the thermocouple pressure gauge at the reactor end of the transfer line from the reactor to the IR measuring cell. However, the IR cell pressure is needed for the calculation of both the gas flow rate and the carbon dioxide mole fraction in the exhaust stream. Therefore, in order to correlate the measured pressures with the IR gas cell pressure, a threaded tee was mounted in the cell and simultaneous readings of the reactor gauge and the IR cell gauge were made. These data appear in Table AP I-4 under the heading, simultaneous IR tc - rxn tc gauges.

Since a McLeod gauge was chosen as the absolute pressure standard and the apparatus was too cumbersome to move, it was necessary to use a portable mechanical vacuum gauge as the intermediary between the standard and the thermocouple gauges. The calibration procedure consisted of attaching this mechanical gauge to the McLeod apparatus, pumping the system to a pressure below 0.01 torr, sealing the system off from the vacuum pump to check for air leaks in the apparatus, and then taking simultaneous readings of the McLeod and mechanical gauges while nitrogen was bled into the apparatus. Nitrogen was used to perform the calibration because it is inert to the mercury of the McLeod gauge.

Once the mechanical gauge was calibrated, it was attached to the side of the threaded tee in the IR cell while the other side held the thermocouple gauge used to measure the IR cell pressure in the calibration mentioned above. The procedure followed was identical to the McLeod calibration with the exception that the gas used was oxygen. Oxygen was used both because it was the reactive gas for the experiment and its use avoided an extra calibration step (air to oxygen). Next the reactor gauge was calibrated to the IR cell gauge using the same technique. Before each reading in these calibrations was taken, the system was allowed to stabilize for 3 minutes at the new pressure level. All of these calibration data are listed on Table AP I-4 .

APPENDIX I-A

Iteration Procedure to Determine Total Pressure

Since a thermal conductivity pressure gauge responds to the thermal conductivity of a gas as well as its pressure, a means must be utilized to remove the gas composition effects from the gauge readings. The tables relating the observed pressure readings to the actual pressure of CO2 or H2O provide part of the solution, Tables AP I-1 and 2. These tables permit any actual partial pressure of carbon dioxide or water vapor to be converted to the observed partial pressure reading on the meter. A second part of the solution is the calibration equation relating observed total pressure at the reactor to the actual total pressure in the infrared measuring cell. (See Appendix I) This equation is,

$$P_{observed\ reactor\ (torr)} = 1.0/0.497 * (P_{actual\ ir} - 0.0027) \qquad (I-1)$$

However, equation (I-1) is limited to the gas used in the calibration, oxygen. Therefore, before using eqn. (I-1), the partial pressure of carbon dioxide and water must be converted to the observed partial pressure on an oxygen basis. This conversion is done using Tables AP I-1 and 2 mentioned above.

The only unknown quantities are the actual partial pressures of carbon dioxide, water, and oxygen. Since the relationship between partial pressures and total pressure is,

$$Ptotal = \sum Yi * Ptotal = (Yco2 + Yh2o + Yo2) * Ptotal \quad (I-2)$$

OR

$$1.0 = Yco2 + Yh2o + Yo2 \quad (I-3)$$

And since equation (I-3) can be simplified by use of the stoichiometric link between carbon dioxide and water vapor,

$$Yh2o = 0.8 * Yco2 \quad (I-4)$$

to yield,

$$Yo2 = 1.0 - 1.8 * Yco2 \quad (I-5)$$

Now a knowledge of the value of Yco2 fixes all of the mole fractions in the IR cell. The only remaining unknowns now are Yco2 and the total pressure in the IR cell. An independent equation relating these two variables is,

$$Yco2 = Cco2 / Ctotal = 24.631 * 760.0 * Cco2 / Ptotal \quad (I-6)$$

where 24.631 is the molar volume of an ideal gas at 27 °C.

Since the concentration of carbon dioxide is a monitored parameter of the system through the absorbance calibration, this iteration scheme is ready for use.

Iteration Procedure (SUBROUTINE PFIND)----------

1. Knowing Cco2, Guess Pir cell
2. Calculate Yco2 from eqn. (I-6)
3. Calculate Yo2 from eqn. (I-5) and Yh2o from eqn. (I-4)
4. Compute partial pressures, Pco2= Yco2*Pir cell, etc.
5. Use the tables (AP I-1 and 2) to determine the observed pressures for CO2 and H2O on an oxygen basis.

   Of course, the observed and partial pressures of O2 are identical.
6. Sum the observed partial pressures.
7. Calculate the observed pressure at the reactor from eqn. (I-1)
8. Compare the monitored value of reactor press. with the calc. value from step 7.
9. If the two values in step 8. differ by more than 0.2%, then Pir cell is adjusted and iteration returns to step 2.

This iteration scheme with trivial modification was used to determine the total IR cell pressure for the calibration of the spectrometer using carbon dioxide - oxygen mixtures. Also this iteration could be generalized for this apparatus and any reacting polymer and product gases

provided that: the exhaust concentration of the product gases was monitored, the stoichiometric ratio of the reactant atoms in the polmer is known, and that the thermal conductivity effect of the gases on the thermocouple gauge is known (Fig. AP I-3).

Of course, this appendix section would have been unnecessary had a composition independent pressure gauge been used. However, pressure transducers for the vacuum region studied (0-10 torr) are very expensive and/or are no more accurate.

TABLE AP I-1

PRESSURE OBSERVED O2 (TORR)	PRESSURE ACTUAL CO2 (TORR)
0.1230E+00	0.8100E-01
0.2330E+00	0.1860E+00
0.3280E+00	0.2780E+00
0.4300E+00	0.3710E+00
0.5500E+00	0.4860E+00
0.6440E+00	0.5850E+00
0.7500E+00	0.6870E+00
0.8620E+00	0.7950E+00
0.9820E+00	0.9000E+00
0.1090E+01	0.1020E+01
0.1180E+01	0.1130E+01
0.1300E+01	0.1250E+01
0.1385E+01	0.1360E+01
0.1500E+01	0.1490E+01
0.1625E+01	0.1600E+01
0.1710E+01	0.1725E+01
0.1780E+01	0.1840E+01
0.1900E+01	0.2000E+01
0.2000E+01	0.2190E+01
0.2150E+01	0.2375E+01
0.2630E+01	0.3100E+01
0.3230E+01	0.3900E+01
0.3710E+01	0.4750E+01
0.4250E+01	0.5900E+01
0.4750E+01	0.6200E+01
0.5300E+01	0.8800E+01
0.6500E+01	0.1364E+02

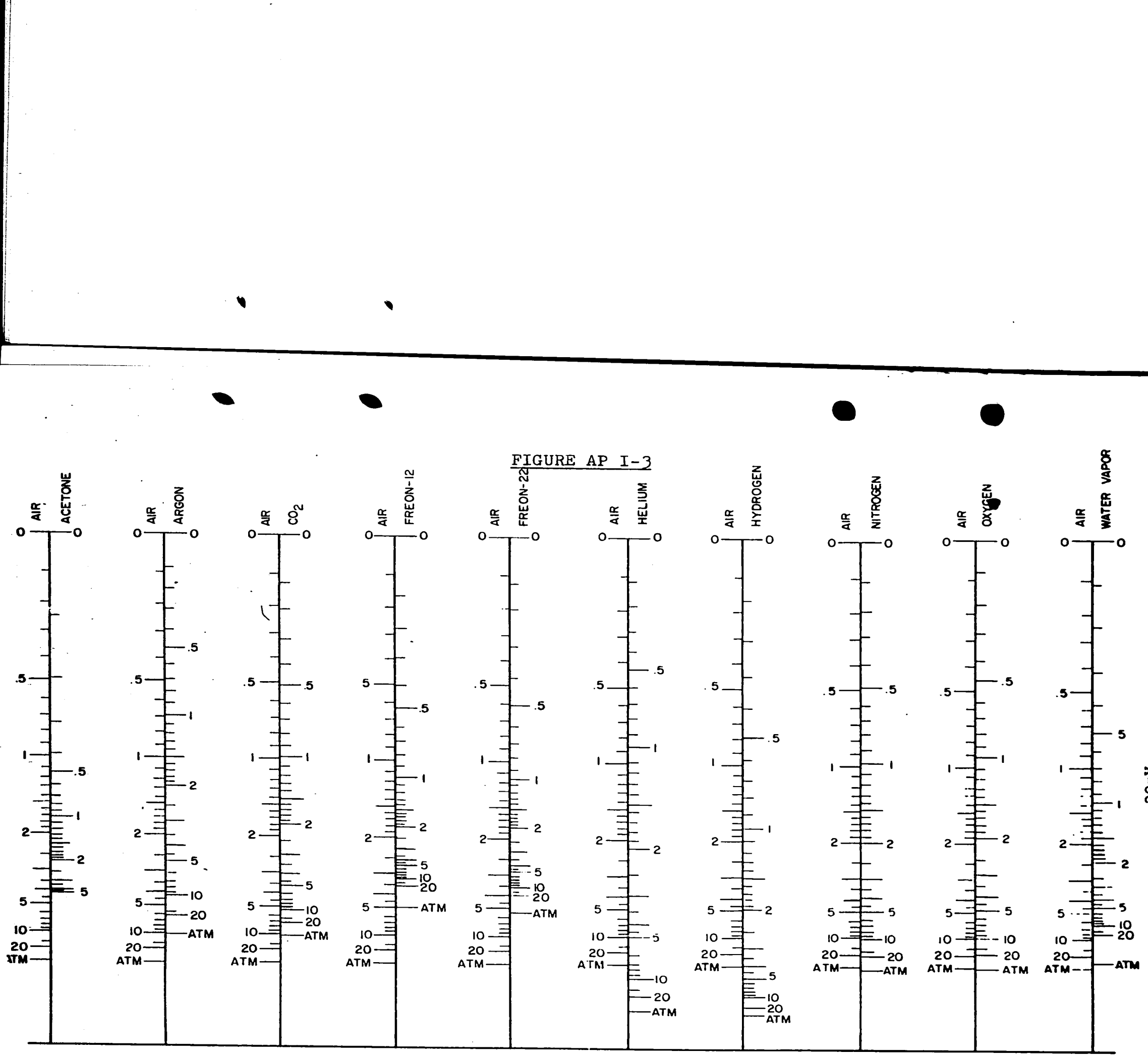
APCO2=0.1596E+00 BPCO2=0.9096E+00 CPCO2=-.3313E-01 STDDEV=0.2024E-01

TABLE AP I-2

PRESSURE OBSERVED O2 (TORR)	PRESSURE ACTUAL H2O (TORR)
0.1230E+00	0.9200E-01
0.2330E+00	0.1730E+00
0.3280E+00	0.2330E+00
0.4300E+00	0.2890E+00
0.5500E+00	0.3570E+00
0.6440E+00	0.4200E+00
0.7500E+00	0.4750E+00
0.8620E+00	0.5500E+00
0.9820E+00	0.6270E+00
0.1090E+01	0.7000E+00
0.1180E+01	0.7700E+00
0.1300E+01	0.8600E+00
0.1385E+01	0.9250E+00
0.1500E+01	0.1040E+01
0.1625E+01	0.1130E+01
0.1710E+01	0.1220E+01
0.1780E+01	0.1315E+01
0.1900E+01	0.1400E+01
0.2000E+01	0.1500E+01
0.2150E+01	0.1590E+01
0.2630E+01	0.2050E+01
0.3230E+01	0.2650E+01
0.3710E+01	0.3300E+01
0.4250E+01	0.4150E+01
0.4750E+01	0.5000E+01
0.5300E+01	0.6000E+01
0.6500E+01	0.7500E+01
0.7500E+01	0.1286E+02
0.8500E+01	0.1900E+02

APH2O=0.3565E+00 BPH2O=0.1049E+01 CPH2O=-.3358E-01 STDDEV=0.4847E-01

FIGURE AP I-3



NOMOGRAM SHOWING CALIBRATION OF HASTINGS VACUUM GAUGES WHICH USE THE DV-4D GAUGE TUBE FOR GASES OTHER THAN AIR. TO FIND THE PRESSURE IN A GAS OTHER THAN AIR, LOCATE THE OBSERVED READING ON THE "AIR" SIDE OF THE APPROPRIATE SCALE AND READ, ON THE OPPOSITE SIDE OF THE SCALE, THE TRUE PRESSURE IN MILLIMETERS OF MERCURY FOR THE GAS BEING MEASURED.

TELEDYNE HASTINGS-RAYDIST
HAMPTON, VIRGINIA

PRINTED IN U.S.A.
JULY 1974

TABLE AP I-4

PRESSURE CALIBRATION DATA

ALL PRESSURES ARE IN TORR

NP IS THE NUMBER OF DATA POINTS TAKEN

NP0=12 NP1= 7 NP2= 9 NCOR= 8

MCLEOD GAUGE	MECHANICAL GAUGE	MECHANICAL GAUGE	IR THERMOCOUPLE GAUGE	IR THERMOCOUPLE GAUGE	REACTOR THERMOCOUPLE GAUGE	SIMULTANEOUS IR TC GAUGE	SIMULTANEOUS RXN TC GAUGE
1.0000	0.8000	2.0000	3.1000	0.7500	0.9600	0.9300	1.2500
1.9000	1.8000	2.2000	3.1500	1.0000	1.3000	1.1500	1.6000
3.0000	2.9500	2.3000	3.3000	1.1500	1.3700	2.8500	4.0000
4.0000	4.2000	2.5000	3.6000	1.2000	1.6000	3.5500	4.9500
5.0000	5.3000	2.7000	3.8500	1.8600	2.3500	4.2500	6.0000
5.9000	6.3000	4.3500	5.8000	1.9500	2.4500	4.7000	6.5000
6.6000	7.2000	5.7000	7.6500	4.6000	5.4000	5.0000	7.0500
7.4000	7.9500			4.7000	5.5000	5.6500	8.2000
8.0000	8.7000			7.0000	8.6500		
8.2000	8.8000						
9.0000	9.7000						
9.6000	10.4000						

SLOPE PM0= 0.8931 INTERCEPT PB0= 0.2849 FIT OF LINE= 0.9998

SLOPE PM1= 0.8005 INTERCEPT PB1= -0.3752 FIT OF LINE= 0.9989

SLOPE PM2= 0.8335 INTERCEPT PB2= -0.0496 FIT OF LINE= 0.9988

SLOPE PMCOR= 0.6950 INTERCEPT PBCOR= 0.0739 FIT OF LINE= 0.9993

POM= 0.5960 POB= -0.0856 POCIRM= 0.4969 POCIRB= 0.0027

APPENDIX II

Calibration of the Iron-Constantan Thermocouples and the Infrared Pyrometer

In order to calibrate the temperature measuring equipment, a controlled temperature plate ("hot chuck") was obtained. This instrument is a Rucker and Kolls model 135 hot chuck probe station which consists of a flat metal disc into which two heating elements and an iron- constantan thermocouple are inserted, and an API model 227 solid state temperature controller. The API controller drives the heating elements based on an error signal between the thermocouple and the controller set point (set point range= 0-300 deg. c). Stability of the controller is a temperature of 151.3 ± 1.1 deg. C (8.08 ± 0.06 millivolts) at the low end of the range, whereas at the high end temperature stability was 266.1 ± 2.2 deg. C (14.45 ± 0.12 millivolts). The calibration was accomplished by melting a small amount of a pure chemical on the surface of the hot chuck. Chemicals were chosen which had melting points over the temperature region of this study: Ice m.p. 0 deg. C, Water b.p. 100 deg. C, Indium m.p. 156.4 deg. C, Silver Nitrate m.p. 212 deg. C, and Bismuth m.p. 271.3 deg. C. These calibration data are recorded in Table AP II-2 and plotted on Fig. AP II-3. In order to calibrate the other thermocouples to the hot chuck, it was only necessary to attach the experimental ther-

mocouples to the chuck and chart the calibrated chuck thermocouple against the new unit. Both the reactor and exhaust gas thermocouples read identically during calibration. This data is plotted in Fig. AP II-5.

In calibrating the IR pyrometer to the hot chuck thermocouple, the method consisted of attaching an unoxidized silicon wafer to the hot chuck surface, focusing the pyrometer on the wafer, and reading the thermocouple versus the pyrometer at an "assumed" silicon emissivity of 0.45. Comparing the thermocouple data and pyrometer readings, a better choice of effective emissivity was made. During these initial setup operations, the pyrometer developed a defective chopper, and subsequently was repaired. Therefore, it was necessary to repeat the emissivity calibration described above. The effective emissivity was now found to be 0.50 (See Fig. AP II-4). This value is closer to the literature value of the emissivity (i.e. e= 0.65, F.G. Allen BTL-AL, Memorandum, 1957) than was the earlier optimum, e=0.31, and was therefore considered more accurate.

FIGURE AP 11-1

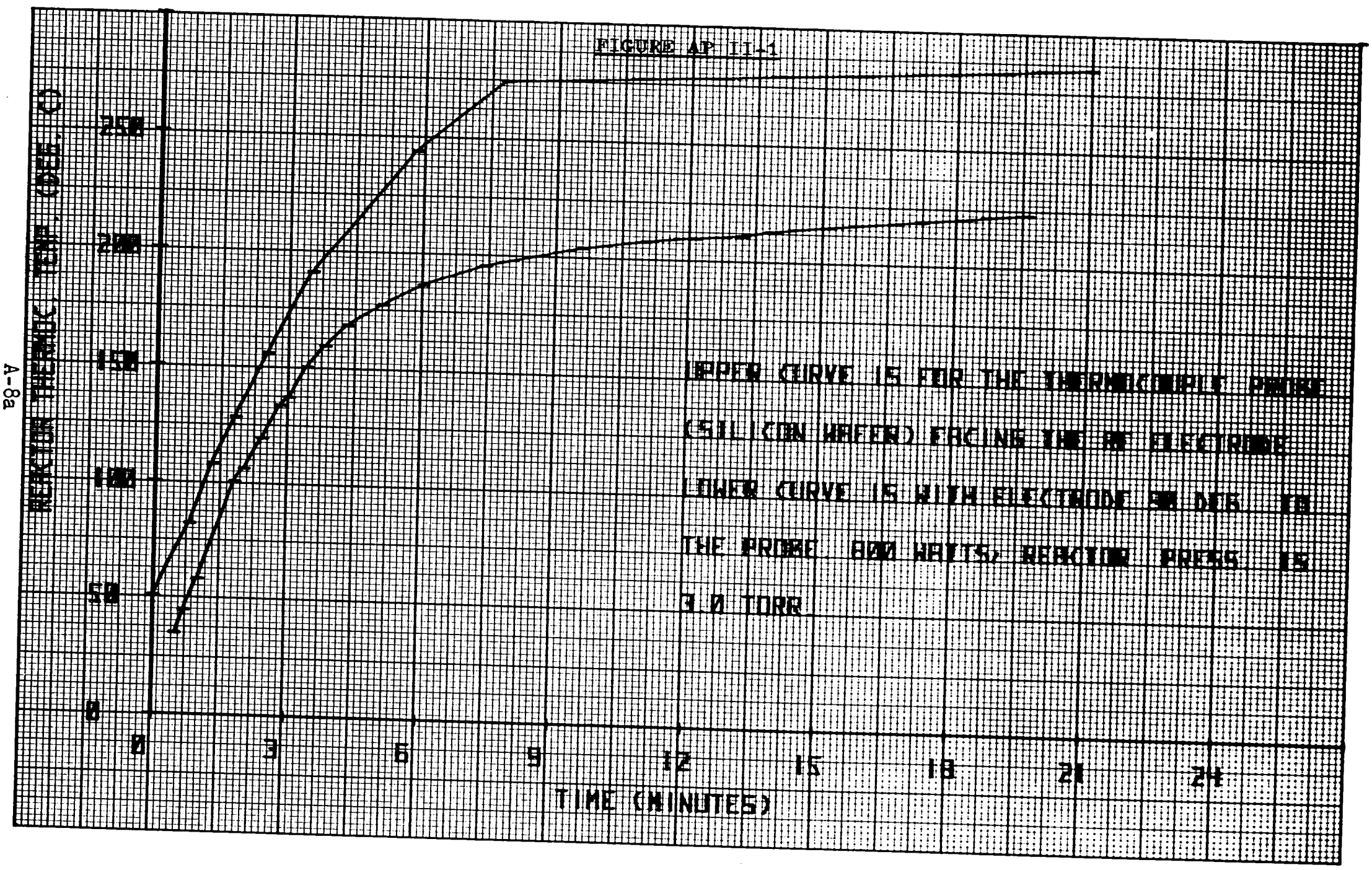


TABLE AP II-2

TEMPERATURE CALIBRATION DATA

ALL TEMPERATURES ARE IN DEG. C

NT IS THE NUMBER OF DATA POINTS TAKEN

NTO= 5 NTI= 8

CHEM MELTING POINT(DEG C)	HOT CHUCK TEMPERATURE	HOT CHUCK TEMPERATURE	IR PYROMETER
0.0	0.0	136.1000	135.0000
100.0000	81.4000	155.2800	156.5000
156.4000	151.6600	179.4400	182.0000
212.0000	201.6600	205.8300	208.5000
271.3000	266.3899	232.5000	235.0000
		258.6001	260.5000
		284.1699	286.0000
		303.8899	305.0000

SLOPE TMO= 1.0050 INTERCEPT TBO= 7.0165 FIT OF LINE= 0.9977

SLOPE TMI= 0.9922 INTERCEPT TBI= 0.1318 FIT OF LINE= 0.9998

TOM= 0.9972 TOB= 7.1489

K•Σ 20 [illegible] TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.

46 1240

FIGURE AP II-3

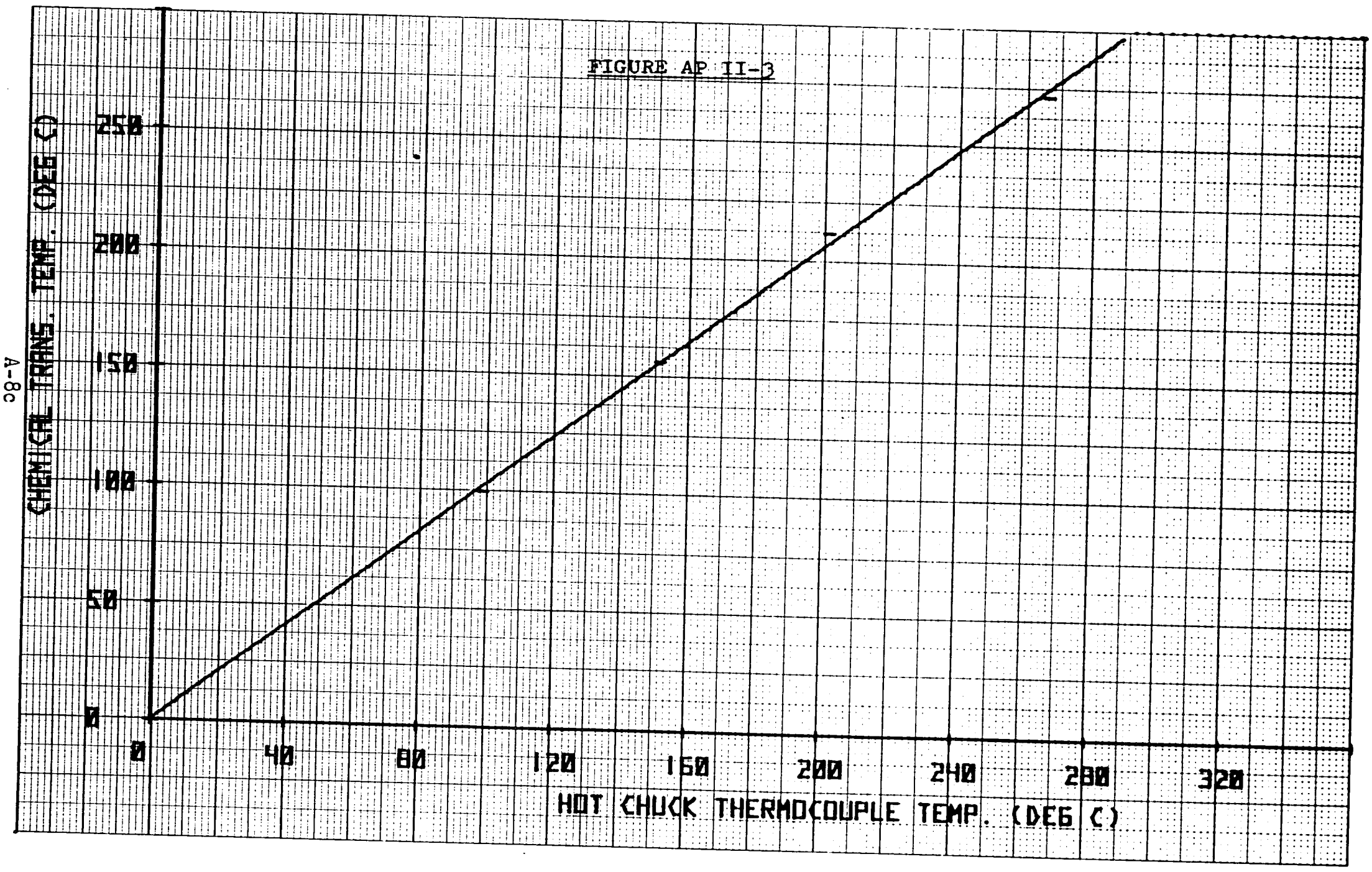
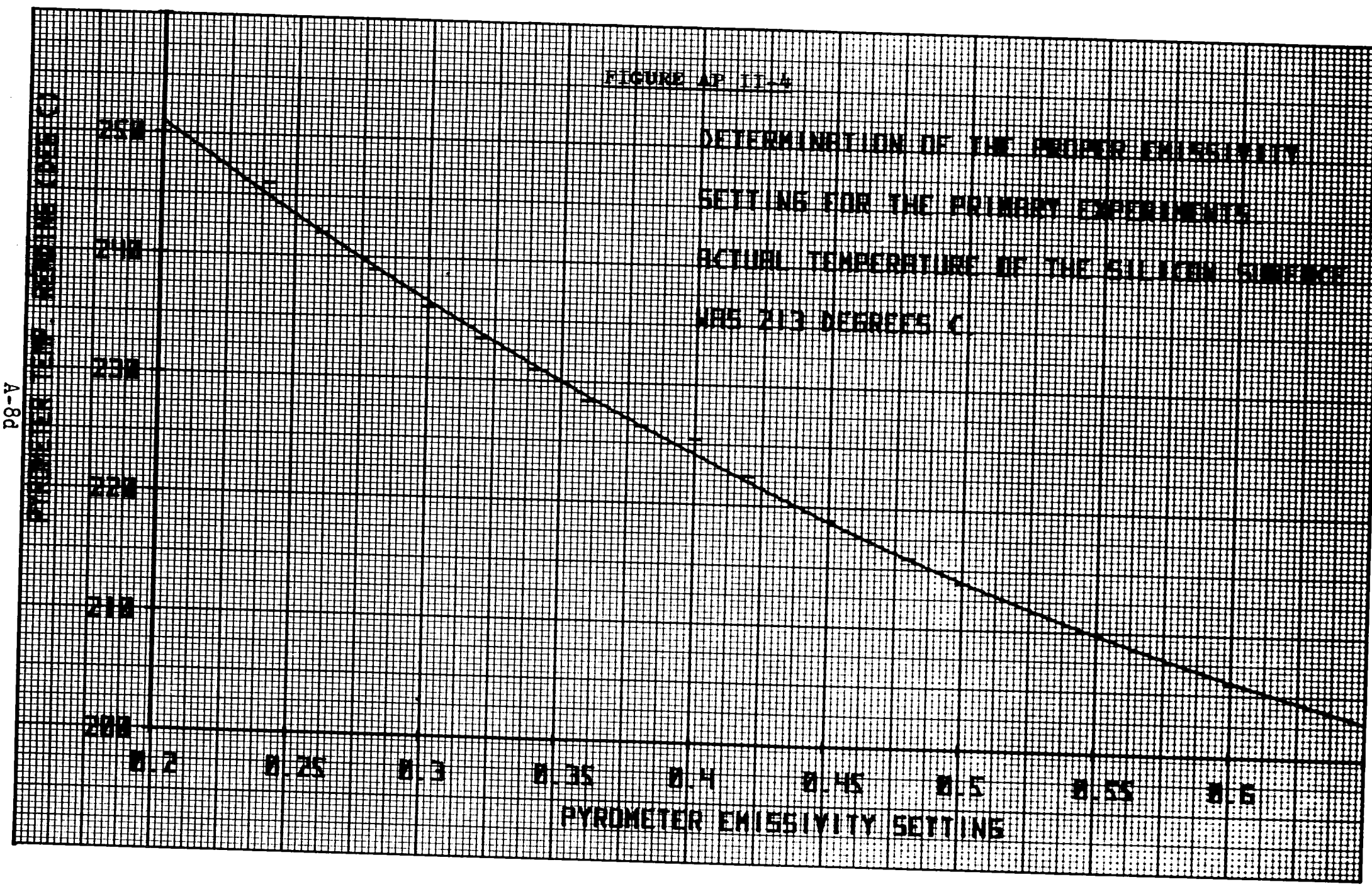


FIGURE AP II-4

DETERMINATION OF THE PROPER EMISSIVITY SETTING FOR THE PRIMARY EXPERIMENTS

ACTUAL TEMPERATURE OF THE SILICON SURFACE WAS 213 DEGREES C



K+E 20 X TO THE INCH 46 1240
7 X IES MADE IN U. S. A.
KEUFFEL & ESSER CO.

FIGURE AF III-5

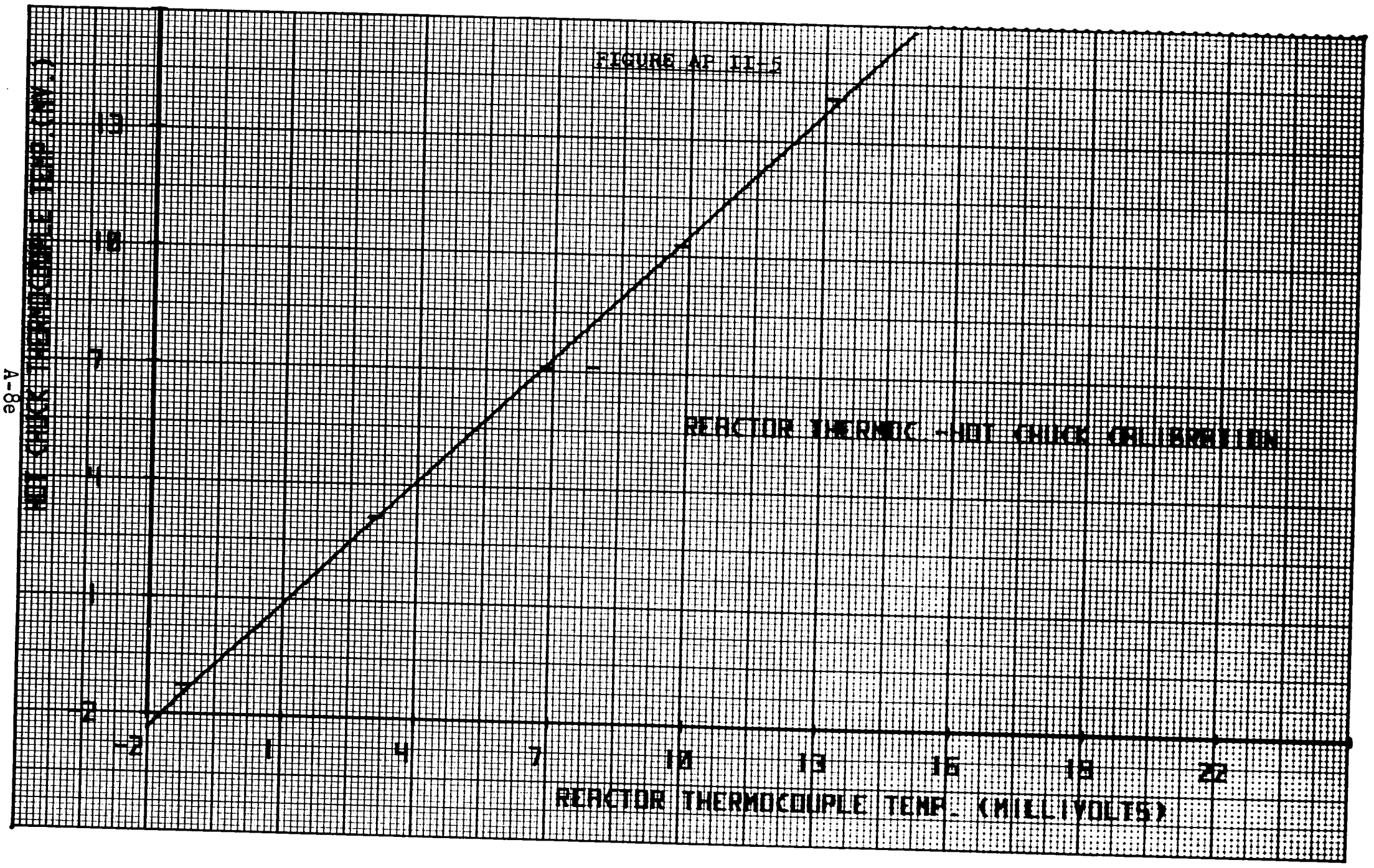


FIGURE AP 11-6

THERMOCOUPLE MEASUREMENT OF EXHAUST
GAS TEMPERATURE AT 800 WATTS
WITH NO REACTION
DATA GAPS DUE TO RF INTERFERENCE

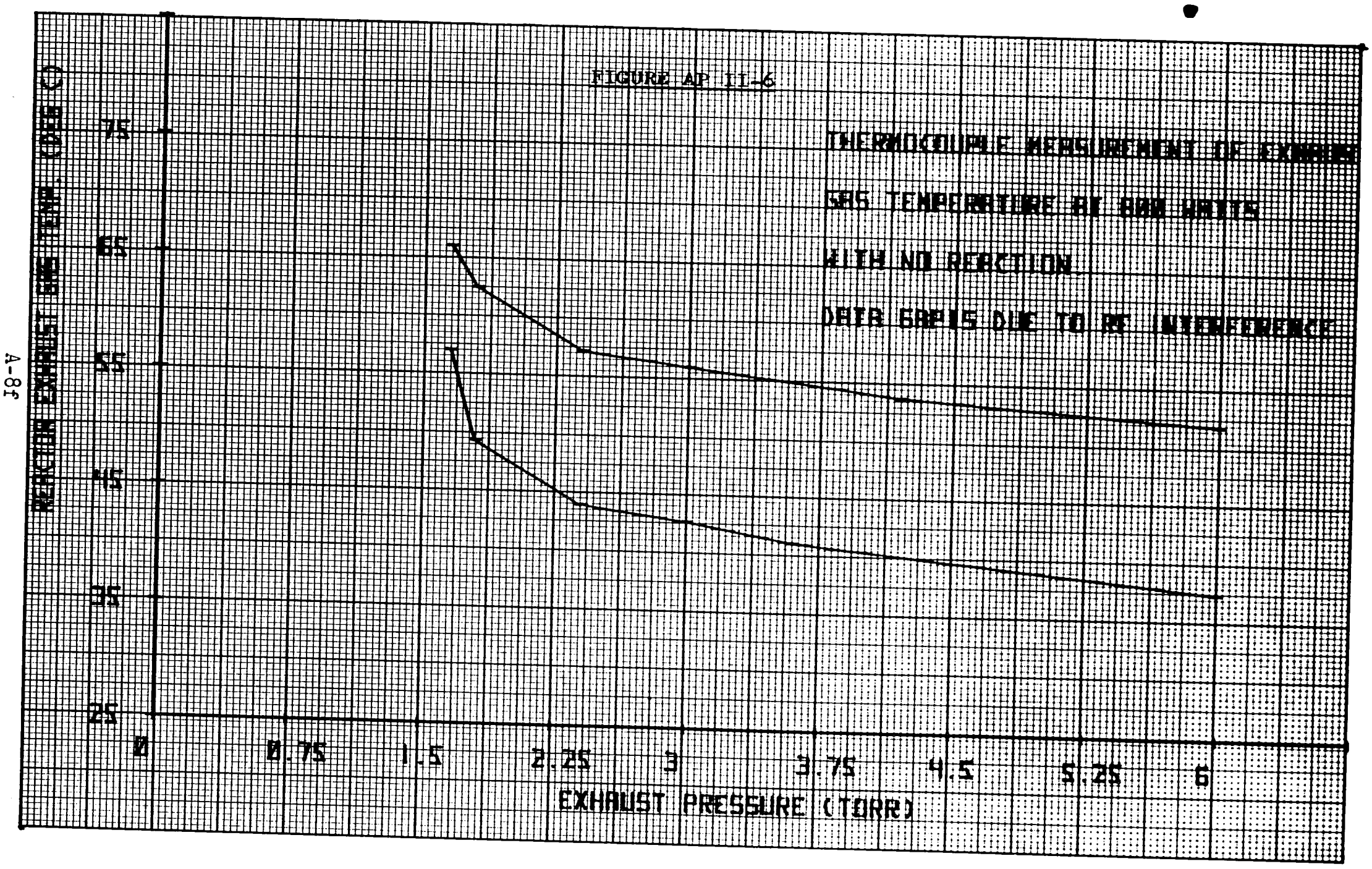


FIGURE AP III-1

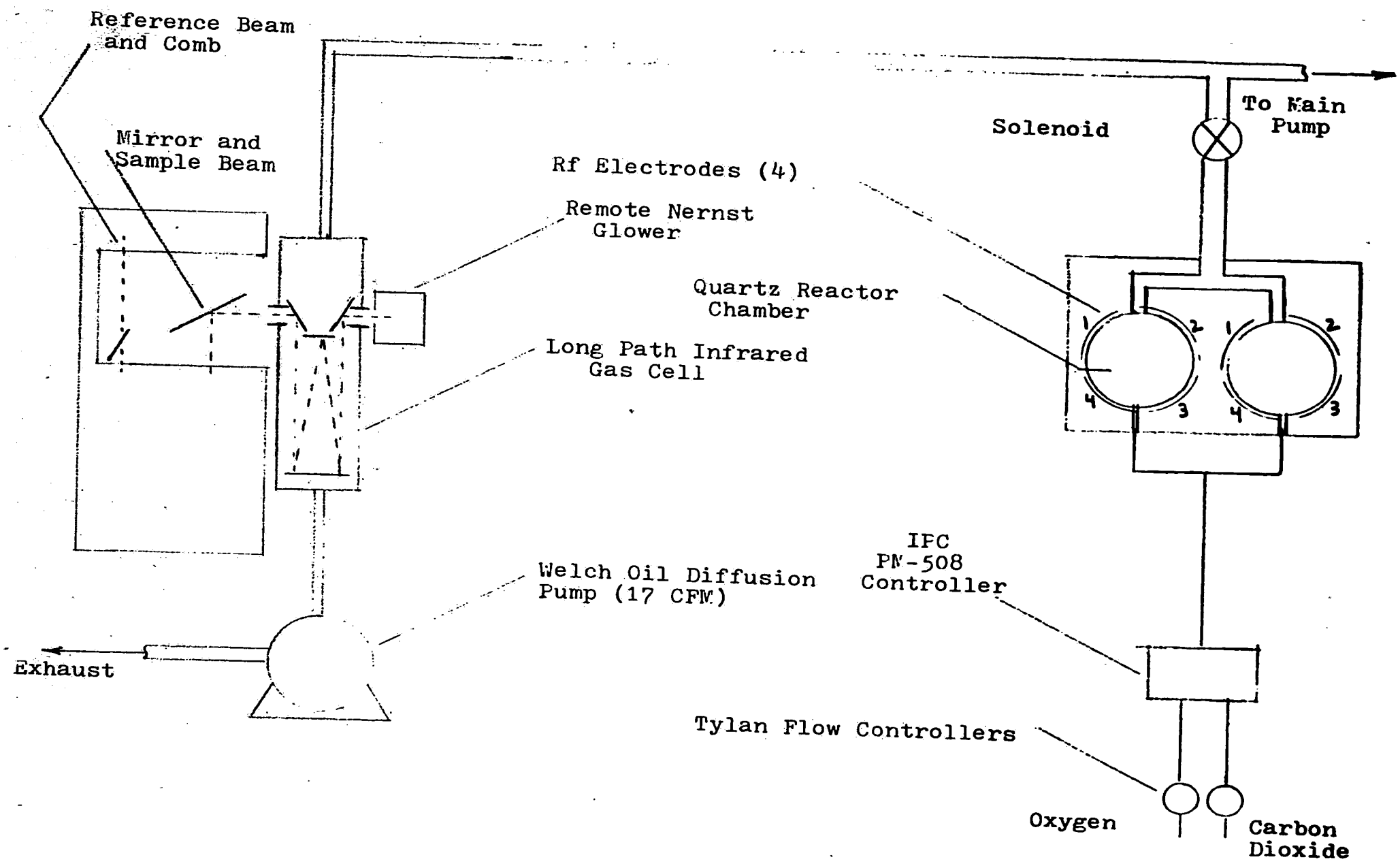
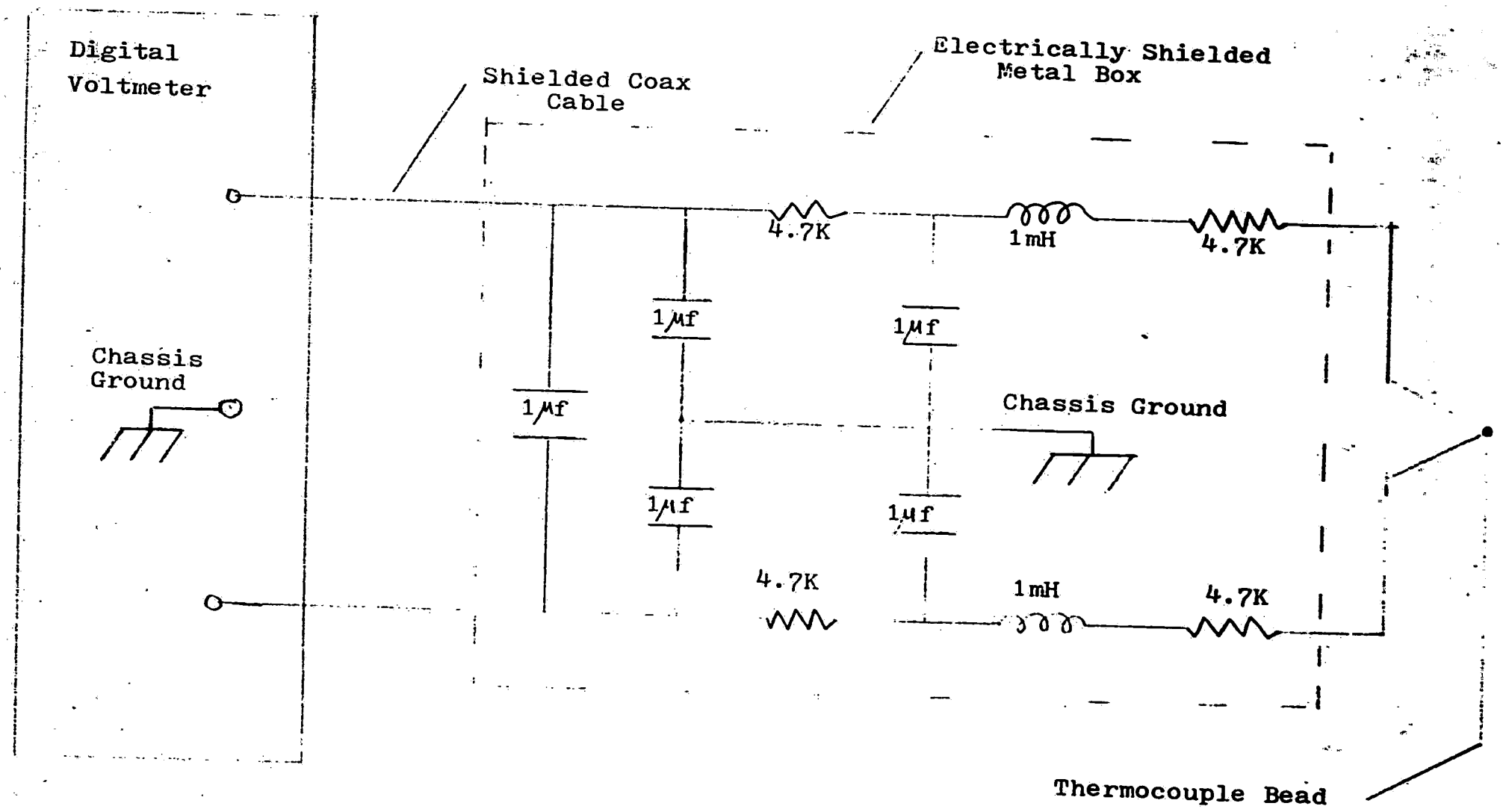


FIGURE AP III-2



APPENDIX IV

Calibration of the Tylan Mass Flow Controllers

Although the primary (absolute) standard for flow calibration is measured liquid displacement for an interval of time, this technique was not used. It was decided that a calibrated Brooks ball and tube flowmeter would be accurate enough for this work. The Brooks R-2-15-D tube with a glass ball was used by connecting it in series with the mass flow controller being calibrated. Since the controller is driven by a 0-5 volt DC signal , an external power supply was used to drive the controller while a digital voltmeter read both this external signal supplied to the controller and the controller response in volts. Ideally, both the control voltage and the signal put out by the controller (in response to the control voltage) will be identical. However, for the high flow region of the carbon dioxide controller, significant deviation from ideality was measured, Table AP IV-2. Also monitored to complete the calibration was the height of the ball in the graduated tube and the flow displayed by the controller, Table AP IV-2 and 3. Nitrogen gas was used for the calibration because its controller correction factor is the same as oxygen, 1.00. Conversion of the ball height measurement to actual flow was done with the Brooks calibration curve for the R-2-15-D tube.

TABLE AP IV-1

CONVERSION FACTORS

DESCRIPTION	SYMBOL	Specific Heat, Cp Cal/gm-°C	Density g/100°C	Conversion Factor
Acetylene	C2H2	.383	1.1709	.61
Air	--	.248	1.2929	1.00
Ammonia	NH3	.5232	.7710	.68
Argon	A	.1253	1.7837	1.36
Arsine	AsH3	.118	3.484	.66
Carbon Dioxide	C02	.1989	1.9769	.74
Carbon Monoxide	C0	.2478	1.2504	1.00
Chlorine	CL2	.115	3.214	.79
Diborane	B2H6	.5012	1.2352	.44
Dichlorosilane	H2SiCL2	.080	4.74	.72
Ethane	C2H6	.4097	1.3566	.49
Ethylene	C2H4	.3592	1.2604	.60
Germane	GeH4	.1335	3.43	.60
Helium*	He	1.248	.1785	1.43
Hydrogen*	H2	3.389	.0899	1.02
Hydrogen Bromide	HBr	.0820	3.6445	1.04
Hydrogen Chloride	HCL	.1939	1.6392	.98
Hydrogen Selenide	H2Se	.100	3.612	.81
Krypton	Kr	.0600	3.700	1.49
Methane	CH4	.5271	.7168	.72
Nitric Oxide	N0	.2328	1.3407	.99
Nitrogen	N2	.2477	1.2506	1.00
Nitrous Oxide	N20	.2004	1.997	.73
Oxygen	02	.2177	1.4290	1.00
Phosphine	PH3	.261	1.5178	.69
Propane	C3H8	.3882	2.0199	.35
Propylene	C3H6	.3541	1.46	.53
Silane	SiH4	.3186	1.44	.59
Silicon Tetrachloride	SiCL4	.169	7.569	.21
Sulfur Dioxide	S02	.1516	2.927	.66
Sulfur Hexafluoride	SF6	.1590	6.139	.28
Tungsten Hexafluoride	WF6	.0954	13.296	.22
Xenon	Xe	.0400	5.897	1.36

Each flow controller is calibrated at the factory for a particular gas and flow range as etched on the outside surface. For conversion to another gas, multiply the output reading by the ratio of the conversion factor (above) for the desired gas to the conversion factor for the calibrated gas.

For example:

Controller calibrated for oxygen
When flow is argon, output reads 50 SCCM

$$\text{Corrected flow} = 50 \times \frac{1.36}{1.00} = 68 \text{ SCCM of argon}$$

*Conversion of controller to or from hydrogen or helium may seriously alter dynamic response or stability.

NOTE: Standard Pressure is defined as 760 mmHg (14.7 psig). Standard Temperature is defined as 0°C as of 4/1/73. (Previous to this date was 59°F).

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TABLE AP IV-2

Calibration Data for the Carbon Dioxide Mass Flow Controller

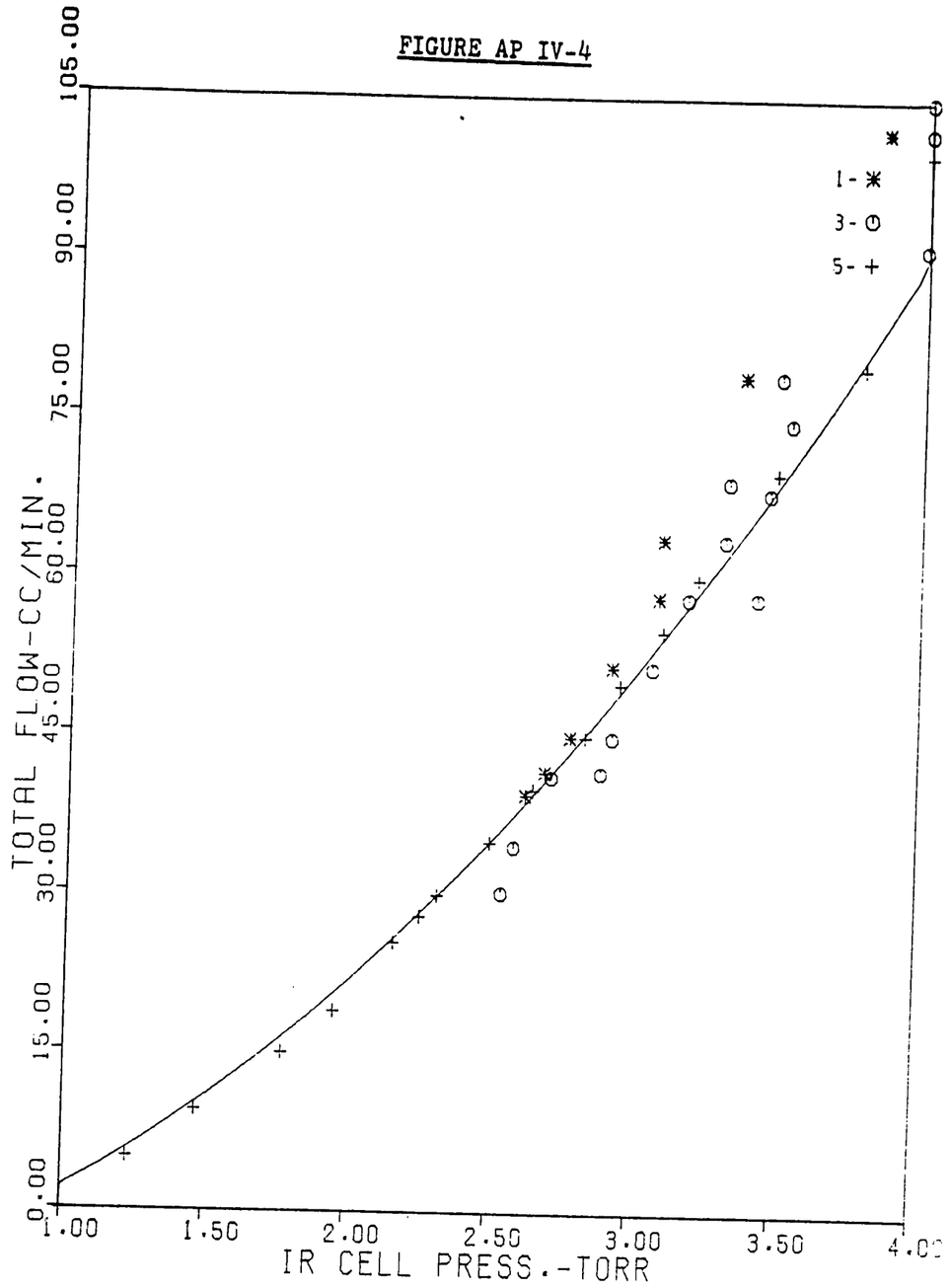
Controller Display (cc/min.)	Control Voltage (volts DC)	Display Voltage (volts DC)	Ball Height (cm.)	O2 Flow Corresponding to Ball Height (70 F) (cc/min.)
140	5.0	4.05	10.5	220
---	4.5	3.90	10.25	214
---	4.0	3.88	10.20	214
135	3.5	3.50	9.70	195
115	3.0	3.00	8.80	166
96	2.5	2.5	8.00	142
77	2.0	2.0	7.10	116
57	1.5	1.5	6.0	87
38	1.0	1.0	4.75	58
---	0.75	0.74	3.9	44.5
---	0.60	0.59	3.4	35
19.5	0.50	0.49	2.85	28
11.5	0.30	0.29	----	----
---	0.25	0.24	1.5	14
3.5	0.10	0.09	0.5	7

TABLE AP IV-3

Calibration Data for the Oxygen Mass Flow Controller

Controller Display (cc/min.)	Control Voltage (volts DC)	Display Voltage (volts DC)	Ball Height (cm.)	O2 Flow Corresponding to Ball Height (70 F) (cc/min.)
205	5.0	5.0	12.5	290
---	4.5	4.5	11.5	255
---	4.0	4.0	10.5	220
---	3.5	3.5	9.75	195
---	3.0	3.0	9.0	170
103	2.5	2.5	8.0	140
---	2.0	2.0	7.0	112
---	1.5	1.5	6.0	87
---	1.0	1.0	4.75	58
---	0.5	0.5	3.0	28
---	0.0	0.0	0.0	0

FIGURE AP IV-4



THIS PLOT SHOWS THE TOTAL FLOW OF CO2 PLUS O2 VERSUS IR CELL PRESSURE FOR THE TWO TRANSMITTANCE CALIBRATION RUNS AND A MEASUREMENT OF FLOW VS. PRESSURE FOR O2. SYMBOL1 IS CALIBRATION1. SYMBOL3 IS CALIBRATION2, AND SYMBOL5 IS THE FLOW VS. PRESS. CURVE USED IN THE CALCULATIONS. THE LINES ON THIS PLOT WERE CALCULATED FROM THE RELATIONSHIP Y=A+B*X+C*X**2 WHERE A,B, AND C ARE CONSTANTS.

SYMBOL1 IS CALIBRATION1 DATA. SYMBOL3 IS DATA FROM CALIBRATION2

DATE 04/25/77 16:32:41

TABLE AP IV-5

Feed Rate O2 (cc/min.)	Pressure IR Cell (torr)	Feed Rate CO2 (cc/min.)	Pressure IR Cell (torr)	Feed Rate H2O (cc/min.)	Pressure IR Cell (torr)
0.0	0.69	0.0	0.58	0.0	0.58
5.0	1.23	3.70	1.01	6.75	0.90
9.5	1.47	7.03	1.22	15.00	1.35
15.0	1.77	11.47	1.42	22.5	1.72
19.0	1.95	15.54	1.57	29.6	2.0
25.5	2.16	20.0	1.82	38.25	2.39
28.0	2.25	25.9	1.98	45.0	2.65
30.0	2.31	29.6	2.20	90.75	4.60
35.0	2.49	33.3	2.31		
40.0	2.64	37.0	2.44		
45.0	2.82	37.74	2.53		
50.0	2.94	44.4	2.62		
55.0	3.09	51.8	2.75		
60.0	3.21	59.2	2.98		
70.0	3.48	74.0	3.23		
80.0	3.78	88.8	3.47		
100.0	4.26				

FIGURE AP IV-6

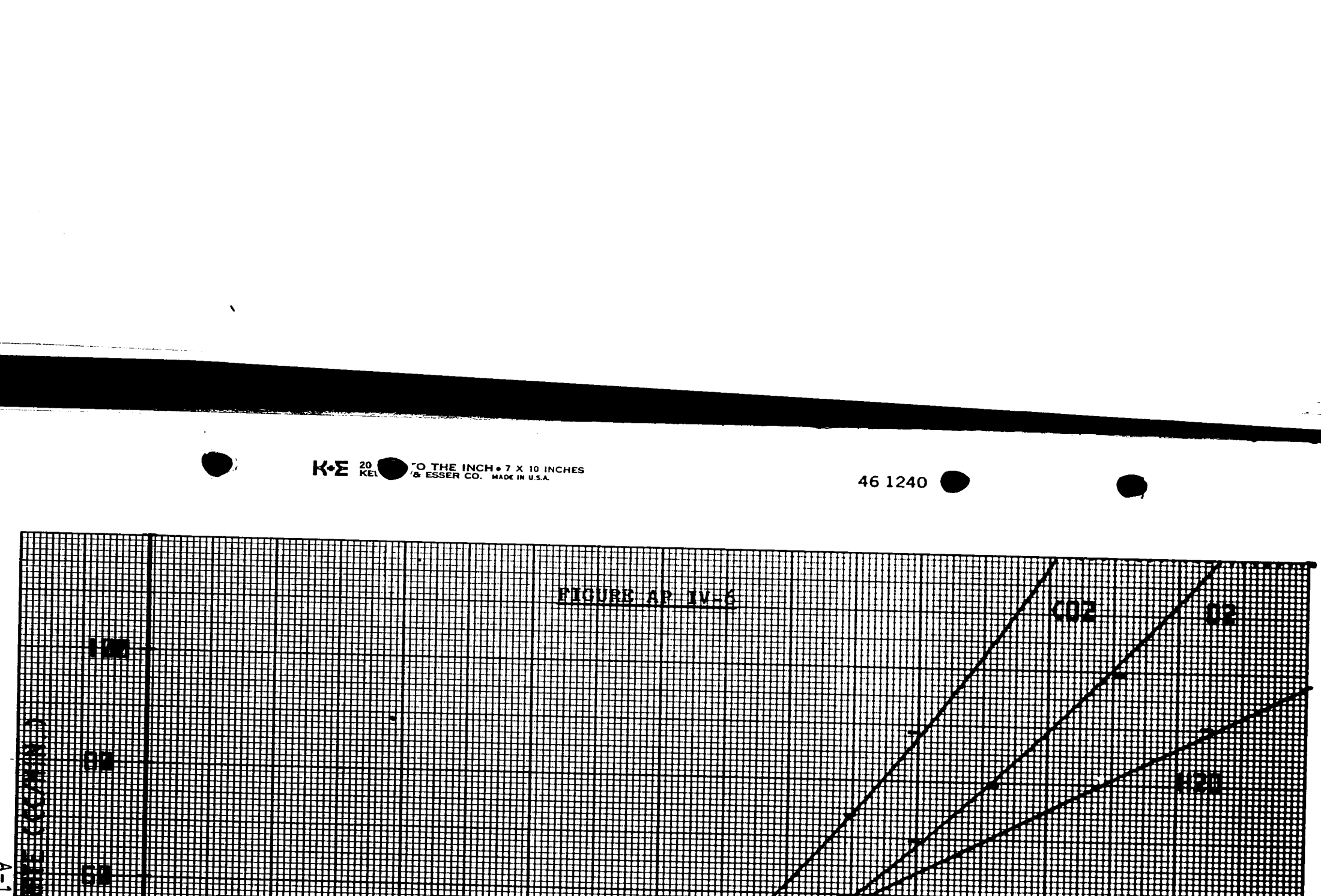


TABLE AP IV-7

FLOW O2 CC/MINUTE	PRESSURE IR-TORR
0.0	0.6900E+00
0.5000E+01	0.1230E+01
0.9500E+01	0.1470E+01
0.1500E+02	0.1770E+01
0.1900E+02	0.1950E+01
0.2550E+02	0.2160E+01
0.2800E+02	0.2250E+01
0.3000E+02	0.2310E+01
0.3500E+02	0.2490E+01
0.4000E+02	0.2640E+01
0.4500E+02	0.2820E+01
0.5000E+02	0.2940E+01
0.5500E+02	0.3090E+01
0.6000E+02	0.3210E+01
0.7000E+02	0.3480E+01
0.8000E+02	0.3780E+01
0.1000E+03	0.4260E+01

FOR TRANS. CAL.18FLOW(Y-AXIS) VS. PRESS.(X-AXIS) COEFS. ARE A=-.7993E+01 B=0.5329E+01 C=0.4789E+01 STDDEV=0.3146E+00

APPENDIX IV-A

Tylan Mass Flow Controller - theory of operation

The temperature of a gas stream is measured before and after a heat source using thermocouples. The difference in these two temperatures is a function of the density, heat capacity, flow rate, and controller configuration. For a given controller and a particular gas, Tylan Corp. adjusts electronically the difference signal, ΔT, so that the ratio, $\Delta T/f(\rho, CP, Kc)$, is equal to the actual volume flow rate in cc/min. at STP flowing through the controller. Once the controller is calibrated at the factory, it should be immune to variations in the environment where it is used since the variations of gas density and heat capacity near room temperature are small.

These Tylan flow controllers can be used with a different gas than the one for which they were calibrated with equal accuracy by adjusting the displayed flows (flow readings) using the conversion factor chart shown in Table AP IV-1. The equation used to derive these factors is,

$$\text{Factor} = K * (0.3098/\rho * CP) \qquad \text{(IV-1)}$$

where K= a constant dependent on gas type; K is 1.04 for monatomic gases, 1.0 for diatomic, 0.94 for triatomic, and 0.88 for polyatomic.

ρ = gas density, grams/liter, at STP (0 °C, 760 mmHg)

CP= gas heat capacity, calories/gram- °C

APPENDIX V

Calibration of the Perkin-Elmer 457 Spectrometer and Infrared Gas Cell

Calibration of the CO2 detection apparatus shown in Fig. AP III-1, consisted of the following: the spectrometer was set at 2349 cm^{-1} by filling the system with CO2 and locating the point of maximum absorbance near 2350 cm^{-1}, the remote Nernst glower variac was set at 90 out of 140, and the secondary or gas cell vacuum pump was turned on. With the gas cell (IR cell) at low pressure, 4-5 torr, the remote glower, IR cell, and concave mirror were adjusted to the maximum obtainable absorbance (minimum transmittance). During these adjustments, the IR cell pathlength was 10 cm. and the "comb" was not in the reference beam. Next the response time of the spectrometer at various gas cell pathlengths. For a cell path of 10 meters, the time for the transmittance to stabilize at a new level after a step change in CO2 concentration (pure O2 to 44% CO2 in oxygen) was 10-12 minutes. This response was far too slow to adequately measure real time CO2 concentration. However, with a pathlength of 6.4 meters, the stabilization time for the same step change was only 3-4 minutes. This time was probably close to the actual mixing time for full changeover of the gas composition. Although shorter pathlengths continued to reduce the response time of the spectrometer, they

attenuated the sensitivity more than could be tolerated in this experiment. Therefore, the IR gas cell was set at 6.4 meters pathlength for all of the experiments.

In order to prevent any doubts about the relationship between calibration and experimental absorbance measurements, the absorbance maximization procedure described above was carried out before calibrations on different days and a recalibration was performed the day when the primary experiments were run. The maximization performed with the IR cell set at 6.4 meters included using the "comb" in the reference beam to attenuate the beam's intensity and hence improve the strength of the measured signal. Usually, the comb was set such that an 80-90 % transmittance baseline was obtained. This transmittance baseline was checked both before and after every experimental run for assurance that the baseline had not drifted.

A cylinder of pure CO2 was used to perform the calibration. Delivery pressure was 5 psig and the gas was at room temperature. This carbon dioxide was supplied to one Tylan flow controller, while oxygen was fed into the other. Both gases were mixed after the flow controllers and fed together through the whole apparatus (reaction chambers, transfer line) to the IR cell. The calibration procedure for the primary experiments consisted of: turning on the flow controllers to a set flow, allowing the system 5 minutes to stabilize before each reading, and then reading flows ,

total pressure, and transmittance simultaneously. While the oxygen flow remained fixed, the CO2 flow was varied over a range of flow from 2-60 cc/min.. Once the range of CO2 flow had been covered, the oxygen flow was changed and the range of CO2 values repeated.

Calculations to reduce the data were the following:

1. Use the flow calibration eqns. (20) and (21) to obtain the actual flows of CO2 and O2.
2. Calculate the mole fraction of CO2, Yco2= CO2 Flow/ Total Flow.
3. Put the relative transmittance readings on an absolute basis by dividing them by the baseline transmittance.
4. Convert the transmittance values to absorbance, A= -log10(Trans.)
5. Calculate the actual IR cell pressure using Appendix I-A.
6. Finally, Calculate the CO2 concentration using the ideal gas molar volume at room temperature (27 ^{o}C).

$$Cco2(gmmoles/liter) = Pgas\ cell/760.0*24.631 \qquad (V-1)$$

where Pgas cell is in torrs.

All the calibration data are charted on Table AP V-1 and graphed on Fig. AP V-2. A least square straight line was fitted to the absorbance vs. concentration data to yield the important relationship,

$$C_{CO_2}(\text{gmmoles/liter}) = 0.0008022 * \text{Absorbance} - 0.00002139 \quad (22)$$

TABLE AP V-1a

TRANSMITTANCE CALIBRATION DATA

THE NUMBER OF DATA POINTS TAKEN= 8

THE BASELINE TRANSMITTANCE (ZERO CO2)= 0.9000

CONCENTRATION IS IN GRAMMOLES/LITER

PRESSURE IS IN TORR

RAW FLOW CO2 CC/MINUTE	RAW FLOW O2 CC/MINUTE	RAW REACTR PRES.-TORR	RELATIVE TRANSMITT.	ABSOLUTE % CO2	ABSOLUTE CONC. CO2	ABSOLUTE TRANSMITT.	ABSOLUTE ABSORBANCE	ABSOLUTE IR PRESS.	TOTAL FLOW CC/MINUTE
0.2400E+02	0.2700E+02	0.6300E+01	0.6900E+00	0.4143E+00	0.6826E-04	0.7667E+00	0.1154E+00	0.3084E+01	0.6362E+02
0.7000E+01	0.2700E+02	0.5700E+01	0.7700E+00	0.1710E+00	0.2527E-04	0.8556E+00	0.6775E-01	0.2766E+01	0.4495E+02
0.5900E+02	0.2700E+02	0.7250E+01	0.5825E+00	0.6349E+00	0.1305E-03	0.6472E+00	0.1889E+00	0.3847E+01	0.1021E+03
0.1900E+02	0.2700E+02	0.6300E+01	0.7250E+00	0.3590E+00	0.5893E-04	0.8056E+00	0.9390E-01	0.3073E+01	0.5812E+02
0.3800E+02	0.2700E+02	0.6700E+01	0.6450E+00	0.5283E+00	0.9486E-04	0.7167E+00	0.1447E+00	0.3361E+01	0.7899E+02
0.4000E+01	0.2700E+02	0.5500E+01	0.8000E+00	0.1055E+00	0.1510E-04	0.8889E+00	0.5115E-01	0.2680E+01	0.4125E+02
0.1300E+02	0.2700E+02	0.6000E+01	0.7600E+00	0.2770E+00	0.4307E-04	0.8444E+00	0.7343E-01	0.2910E+01	0.5154E+02
0.2000E+01	0.2700E+02	0.5350E+01	0.8375E+00	0.5566E-01	0.7765E-05	0.9306E+00	0.3126E-01	0.2611E+01	0.3946E+02

FOR TRANS. CAL. IFLOW(Y-AXIS) VS. PRESS.(X-AXIS) COEFS. ARE A=-.9899E+02 B=0.5229E+02 C=0.0 STDDEV=0.9958E+00

SLOPE CONOM=0.8022E-03 INTERCEPT CONOB=-.2139E-04 FIT OF LINE=0.9935E+00

TABLE AP V-1b

TRANSMITTANCE CALIBRATION DATA

THE NUMBER OF DATA POINTS TAKEN=16

THE BASELINE TRANSMITTANCE (ZERO CO2)= 0.8300

CONCENTRATION IS IN GRAMMOLES/LITER

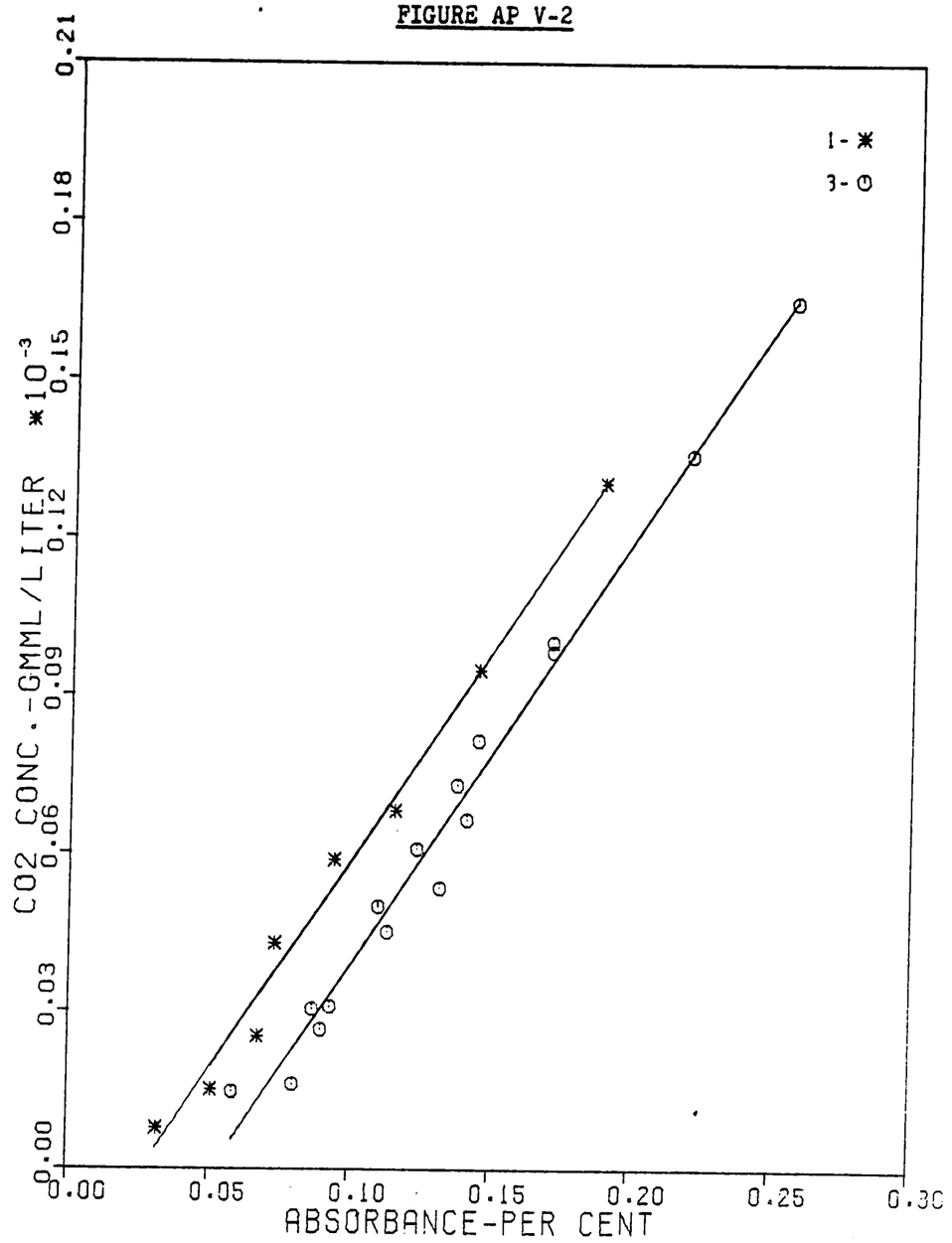
PRESSURE IS IN TORR

RAW FLOW CO2 CC/MINUTE	RAW FLOW O2 CC/MINUTE	RAW REACTR PRES.-TORR	RELATIVE TRANSMITT.	ABSOLUTE % CO2	ABSOLUTE CONC. CO2	ABSOLUTE TRANSMITT.	ABSOLUTE ABSORBANCE	ABSOLUTE IR PRESS.	TOTAL FLOW CC/MINUTE
0.2900E+02	0.2700E+02	0.6700E+01	0.5950E+00	0.4608E+00	0.8151E-04	0.7169E+00	0.1446E+00	0.3311E+01	0.6911E+02
0.3800E+02	0.2700E+02	0.6900E+01	0.5600E+00	0.5283E+00	0.9837E-04	0.6747E+00	0.1709E+00	0.3486E+01	0.7899E+02
0.5900E+02	0.2700E+02	0.7500E+01	0.5000E+00	0.6349E+00	0.1358E-03	0.6024E+00	0.2201E+00	0.4004E+01	0.1021E+03
0.1300E+02	0.2700E+02	0.6300E+01	0.6400E+00	0.2770E+00	0.4519E-04	0.7711E+00	0.1129E+00	0.3054E+01	0.5154E+02
0.7000E+01	0.2700E+02	0.6000E+01	0.6750E+00	0.1710E+00	0.2663E-04	0.8133E+00	0.8977E-01	0.2915E+01	0.4495E+02
0.4000E+01	0.2700E+02	0.5900E+01	0.6900E+00	0.1055E+00	0.1621E-04	0.8313E+00	0.8023E-01	0.2877E+01	0.4165E+02
0.1900E+02	0.2700E+02	0.6500E+01	0.6250E+00	0.3590E+00	0.6092E-04	0.7530E+00	0.1232E+00	0.3177E+01	0.5812E+02
0.2400E+02	0.2700E+02	0.6700E+01	0.6050E+00	0.4143E+00	0.7308E-04	0.7289E+00	0.1373E+00	0.3302E+01	0.6462E+02
0.2400E+02	0.3500E+02	0.7200E+01	0.6000E+00	0.3530E+00	0.6647E-04	0.7229E+00	0.1409E+00	0.3525E+01	0.7466E+02
0.3900E+02	0.3500E+02	0.7900E+01	0.5600E+00	0.4700E+00	0.1002E-03	0.6747E+00	0.1709E+00	0.3991E+01	0.9113E+02
0.8500E+02	0.3500E+02	0.8500E+01	0.4600E+00	0.6590E+00	0.1649E-03	0.5542E+00	0.2563E+00	0.4684E+01	0.1416E+03
0.1800E+02	0.3500E+02	0.7100E+01	0.6130E+00	0.2904E+00	0.5357E-04	0.7386E+00	0.1316E+00	0.3453E+01	0.6807E+02
0.9000E+01	0.3500E+02	0.7000E+01	0.6700E+00	0.1699E+00	0.3100E-04	0.8072E+00	0.9300E-01	0.3416E+01	0.5818E+02
0.3000E+01	0.1950E+02	0.5200E+01	0.7250E+00	0.1091E+00	0.1475E-04	0.8735E+00	0.5874E-01	0.2532E+01	0.3020E+02
0.7000E+01	0.1950E+02	0.5300E+01	0.6800E+00	0.2222E+00	0.3053E-04	0.8193E+00	0.8657E-01	0.2572E+01	0.3460E+02
0.1300E+02	0.1950E+02	0.5600E+01	0.6450E+00	0.3466E+00	0.5004E-04	0.7771E+00	0.1095E+00	0.2702E+01	0.4119E+02

FOR TRANS. CAL. 2FLOW(Y-AXIS) VS. PRESS.(X-AXIS) COEFS. ARE A=-.9665E+02 B=0.4898E+02 C=0.0 STDDEV=0.9819E+00

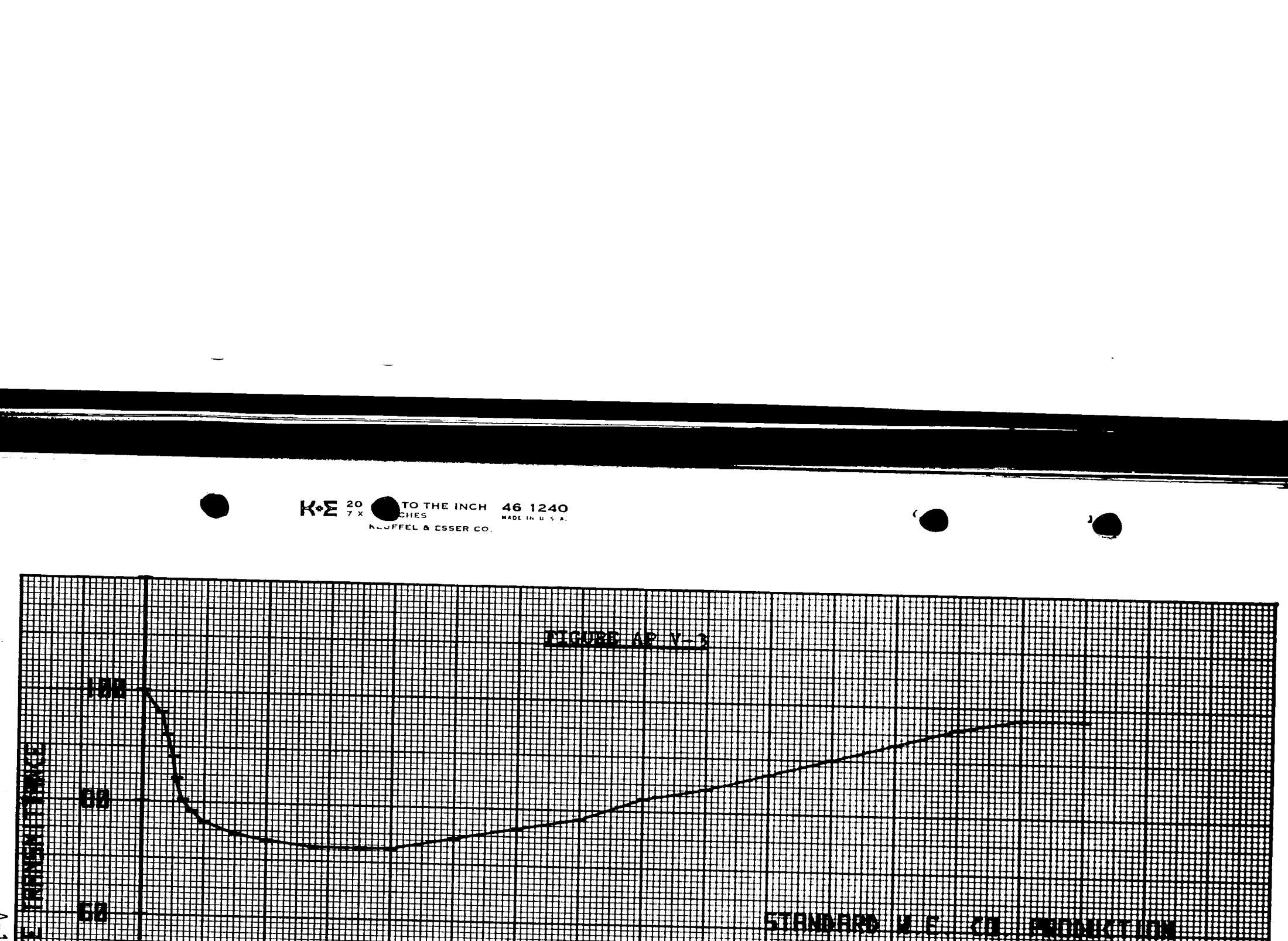
SLOPE CONOM=0.8090E-03 INTERCEPT CONOB=-.4195E-04 FIT OF LINE=0.9921E+00

FIGURE AP V-2



THIS PLOT SHOWS THE ABSORBANCE VS. CO2 CONCENTRATION(GRAMMOLES/LITER) RELATIONSHIP DETERMINED BY THE TRANSMITTANCE CALIBRATION.
THE LINES ON THIS PLOT WERE CALCULATED FROM THE RELATIONSHIP Y=A - B*X WHERE A AND B ARE CONSTANTS

DATE 04/28/77 19:52:03



APPENDIX VI

```
C                                                                       MSDG  1
C     THIS PROGRAM CALCULATES CALIBRATION LINES FOR PRESSURE,WAFER TEMP MSDG  2
C                                                                       MSDG  3
C     ,CO2-O2 FLOW, AND TRANSMITTANCE FOR A SYSTEM CONSISTING OF AN IPC MSDG  4
C                                                                       MSDG  5
C     PLASMA REACTOR MODEL 2000 WITH OUTPUT GAS HOOKED TO AN INFRARED   MSDG  6
C                                                                       MSDG  7
C     0-10 METER PATHLENGTH CELL.  VACUUM IS DRAWN ON THE PLASMA REACT. MSDG  8
C                                                                       MSDG  9
C     THROUGH THE IR CELL BY A 17 CFM  WELCH ROUGHING PUMP. FOLLOWING   MSDG 10
C                                                                       MSDG 11
C     THE CALIBRATION SECTION OF THE PROGRAM, THE INSTRUMENT READINGS   MSDG 12
C                                                                       MSDG 13
C     OF THE EXPERIMENTS ARE CONVERTED TO ABSOLUTE, THEN ALL OF THE     MSDG 14
C                                                                       MSDG 15
C     DATA IS CROSS-CORRELATED FOR EMPIRICAL GRAPHS, RELATIONS, AND     MSDG 16
C                                                                       MSDG 17
C     RATE OF REMOVAL CALCULATIONS.                                     MSDG 18
C                                                                       MSDG 19
      COMMON P0M,P0B,P0CIRM,P0CIRB,T0M,T0B,CON0M,CON0B                  MSDG 20
      COMMON FLOWA,FLOWB,FLOWC                                          MSDG 21
      DIMENSION P0MCL(50),P0MECH(50),P1MECH(50),P1TCIR(50),P2TCIR(50)   MSDG 22
      DIMENSION P2TCRT(50),PCORIR(50),PCORRT(50),T0CHEM(20),T0HCTC(20)  MSDG 23
      DIMENSION T1HCTC(50),T1PYR(50)                                    MSDG 24
      DIMENSION CO2CON(50)                                              MSDG 25
      DIMENSION                    BLINE(10),F2(10), CONM(2),CONB(2)    MSDG 26
      DIMENSION FCREM(2,30),FOREM(2,30),RLTREM(2,30)                    MSDG 27
      DIMENSION PREM(2,30)                                              MSDG 28
      DIMENSION CONF(2),CO2PR(2,30), CO2CN(2,30),ABSRB(2,30),NDATA(10)  MSDG 29
      DIMENSION AA(3),BB(3),CC(3), CDLTOT(10,40),FCO2CB(2,30)           MSDG 30
      DIMENSION FO2CB(2,30), PIRCB(2,30), PRCTCB(2,30),XPLOT(102)       MSDG 31
      DIMENSION YPLOT(102),NTRAN(5),CO2PER(50),ABSORB(50),ABSB(10,40)   MSDG 32
      DIMENSION TIME(10,40), POWLEV(10),WTLOSS(10),PIR(10,40)           MSDG 33
      DIMENSION PREACT(10,40), TPYROM(10,40),CDLSPM(10,40),CDLOSS(10,40) MSDG 34
      DIMENSION TRANS(10,40) ,R(10,40), FLOW2(10,40), YCO2(10,40)       MSDG 35
      DIMENSION DUMX(40),DUMY(40)                                       MSDG 36
      DIMENSION TRUE(10)                                                MSDG 37
      DIMENSION DUMF(40),DUMP(40),EACT(10),FREQF(10),HEATCO(10)         MSDG 38
      DIMENSION TMPZER(10)                                              MSDG 39
      DIMENSION FITTMP(10)                                              MSDG 40
      DIMENSION COABA(10),COABB(10),COABY(10),COPRA(10),COPRB(10)       MSDG 41
      DIMENSION COPRY(10),COTMPA(10) ,COTMPB(10),COTMPY(10),COTOTA(10)  MSDG 42
      DIMENSION COTOTB(10),COTOTC(10)                                   MSDG 43
      DIMENSION CDL(100),FLWA(2),FLWB(2),FLWC(2),FITT(2)                MSDG 44
      DIMENSION POB1(10,40),CO2C(10,40),DCO2DT(10,40),YO2(10,40),       MSDG 45
     1  DUMC(40),DUMH(40)                                               MSDG 46
      DIMENSION DUMO(40),DO2DT(10,40)                                   MSDG 47
      DIMENSION COMNT(240)                                              MSDG 48
      REAL LGLG,LINR                                                    MSDG 49
      DATA FLIP,BLANK/'FLIP','    '/                                    MSDG 50
```

```
      DATA SLGX,SLGY,LINR,LGLG,END/'SLGX','SLGY','LINR','LGLG','END '/  MSDG 51
      CALL PLOTS(0,0,9)                                                 MSDG 52
C     THIS SECTION READS THE CALIBRATION PRESSURE READINGS BETWEEN THE  MSDG 53
C                                                                       MSDG 54
C     ABSOLUTE PRESSURE MCLEOD GAUGE(P0),THE MECHANICAL GAUGE,THE MODEL MSDG 55
C                                                                       MSDG 56
C     DV-4DM HASTINGS-RAYDIST THERMOCOUPLE GAUGES (ONE IN REACTOR,ONE INMSDG 57
C                                                                       MSDG 58
C     IR CELL). IT PERFORMS LINEAR REGRESSIONS TO ENABLE THE REACTOR    MSDG 59
C                                                                       MSDG 60
C     PRESSURE DATA TO BE CONVERTED TO ABSOLUTE REACTOR PRESSURES USING MSDG 61
C                                                                       MSDG 62
C    (FUNCTION P0RT) AND ABSOLUTE IR CELL PRESS. (FUNTION P0IRRT) .     MSDG 63
C                                                                       MSDG 64
      READ(5,10) NP0                                                    MSDG 65
   10 FORMAT(I2)                                                        MSDG 66
      READ(5,15) (P0MCL(I),P0MECH(I),I=1,NP0)                           MSDG 67
   15 FORMAT(4(2F10.4))                                                 MSDG 68
      READ(5,10) NP1                                                    MSDG 69
      READ(5,15)  (P1MECH(I),P1TCIR(I),I=1,NP1)                         MSDG 70
C                                                                       MSDG 71
      READ(5,10) NP2                                                    MSDG 72
      READ(5,15)  (P2TCIR(I),P2TCRT(I),I=1,NP2)                         MSDG 73
C                                                                       MSDG 74
      READ(5,10) NCOR                                                   MSDG 75
      READ(5,15)  (PCORIR(I),PCORRT(I),I=1,NCOR)                        MSDG 76
C                                                                       MSDG 77
      WRITE(6,40)                                                       MSDG 78
      WRITE(6,41)  NP0,NP1,NP2,NCOR                                     MSDG 79
   40 FORMAT(1H1,50X,'PRESSURE CALIBRATION DATA'/1X,49X,25('-')//,      MSDG 80
     1  42X, 'ALL PRESSURES ARE IN TORR'//)                            MSDG 81
C                                                                       MSDG 82
                                                                        MSDG 83
   41 FORMAT(42X,'NP IS THE NUMBER OF DATA POINTS TAKEN'///1X,11X,'NP0='MSDG 84
     1 ,I2,12X,12X,'NP1=',I2,24X,'NP2=',I2,24X,'NCOR=',I2///1X)         MSDG 85
C                                                                       MSDG 86
      WRITE(6,854)                                                      MSDG 87
      WRITE(6,855)                                                      MSDG 88
      WRITE(6,856)                                                      MSDG 89
      WRITE(6,857)                                                      MSDG 90
C                                                                       MSDG 91
C    WRITE OUT THE PRESSURE CALIBRATION DATA                            MSDG 92
C                                                                       MSDG 93
C                                                                       MSDG 94
  854 FORMAT(1X,42X,9X,'IR',13X,'IR',11X,'REACTOR',11X,'SIMULTANEOUS')  MSDG 95
C                                                                       MSDG 96
  855 FORMAT(1X,4X,'MCLEOD',7X,'MECHANICAL',5X,'MECHANICAL',4X,'THERMOCOMSDG 97
     1UPLE',3X,'THERMOCOUPLE',3X,'THERMOCOUPLE',7X,'IR TC',9X,'RXN TC')  MSDG 98
C                                                                       MSDG 99
  856 FORMAT(1X,4X,'GAUGE',5X,7(5X,'GAUGE',5X))                         MSDG100
C                                                                       MSDG101
  857 FORMAT(1X,1X,11('-'),2X,7(2X,11('-'),2X))                         MSDG102
C                                                                       MSDG103
C                                                                       MSDG104
```

```
      DO 68 KK=1,50
      IF(KK.GT.NP0.AND.KK.GT.NP1.AND.KK.GT.NP2 .AND.KK.GT.NCOR) GO TO 69  MSDG105
      WRITE(6,50)                                                         MSDG106
   50 FORMAT(1H )                                                         MSDG107
   52 FORMAT(1H+,    F10.4,5X,F10.4,2X)                                   MSDG108
   53 FORMAT(1H+,30X,F10.4,5X,F10.4,2X)                                   MSDG109
   54 FORMAT(1H+,60X,F10.4,5X,F10.4,2X)                                   MSDG110
   55 FORMAT(1H+,90X,F10.4,5X,F10.4,2X)                                   MSDG111
C                                                                         MSDG112
C                                                                         MSDG113
      DO 200 KKK=1,4                                                      MSDG114
C                                                                         MSDG115
      GO TO(201,202,203,204),KKK                                          MSDG116
C                                                                         MSDG117
      GO TO 200                                                           MSDG118
  201 IF(KK.GT.NP0) GO TO 200                                             MSDG119
      WRITE(6,52) P0MCL(KK),P0MECH(KK)                                    MSDG120
  202 IF(KK.GT.NP1) GO TO 200                                             MSDG121
      WRITE(6,53) P1MECH(KK),P1TCIR(KK)                                   MSDG122
      GO TO 200                                                           MSDG123
  203 IF(KK.GT.NP2) GO TO 200                                             MSDG124
      WRITE(6,54) P2TCIR(KK),P2TCRT(KK)                                   MSDG125
      GO TO 200                                                           MSDG126
  204 IF(KK.GT.NCOR) GO TO 200                                            MSDG127
      WRITE(6,55) PCORIR(KK),PCORRT(KK)                                   MSDG128
C                                                                         MSDG129
C                                                                         MSDG130
  200 CONTINUE                                                            MSDG131
   68 CONTINUE                                                            MSDG132
   69 CONTINUE                                                            MSDG133
C                                                                         MSDG134
CC   LINEAR REGRESSION ANALYSIS OF PRESSURE DATA                          MSDG135
C                                                                         MSDG136
C                                                                         MSDG137
      CALL REGLNR(P0MCL,P0MECH,NP0,PM0,PB0,PFIT0)                         MSDG138
      CALL REGLNR(P1MECH,P1TCIR,NP1,PM1,PB1,PFIT1)                        MSDG139
      CALL REGLNR(P2TCIR,P2TCRT,NP2,PM2,PB2,PFIT2)                        MSDG140
C                                                                         MSDG141
      P0= M0*(M1*(M2*PRT + B2) + B1) + B0                                 MSDG142
C                                                                         MSDG143
      P0M=PM0*PM1*PM2                                                     MSDG144
      P0B=PM0*PM1*PB2 + PM0*PB1 + PB0                                     MSDG145
C                                                                         MSDG146
      CALL REGLNR(PCORIR,PCORRT,NCOR,PMCOR,PBCOR,PFITC)                   MSDG147
C                                                                         MSDG148
      P0IR= M0*(M1*(MCOR*PRT + BCOR) + B1) + B0                           MSDG149
C                                                                         MSDG150
      P0CIRM=PM0*PM1*PMCOR                                                MSDG151
      P0CIRB=PM0*PM1*PBCOR + PM0*PB1 + PB0                                MSDG152
C                                                                         MSDG153
C                                                                         MSDG154
      WRITE(6,66)                                                         MSDG155
      WRITE(6,70) PM0,PB0,PFIT0,PM1,PB1,PFIT1,PM2,PB2,PFIT2,PMCOR,PBCOR,  MSDG156
     1 PFITC                                                              MSDG157
                                                                          MSDG158
```

```
C
   66  FORMAT(1X,//)                                                        MSDG159
   70 FORMAT(1X,19X,'SLOPE PM0=',F10.4,5X,'INTERCEPT PB0=',F10.4,5X,       MSDG160
     1 'FIT OF LINE=',F10.4//1X,19X,  'SLOPE PM1=',F10.4,5X,'INTERCEPT     MSDG161
     2PB1=',F10.4,5X, 'FIT OF LINE=',F10.4//1X,19X, 'SLOPE PM2=',F10.4,    MSDG162
     3 5X, 'INTERCEPT PB2=',F10.4,5X, 'FIT OF LINE=',F10.4//1X,19X,        MSDG163
     4 'SLOPE PMCOR=',F10.4,5X, 'INTERCEPT PBCOR=',F10.4,5X,               MSDG164
     5 'FIT OF LINE=', F10.4////)                                          MSDG165
C                                                                          MSDG166
      WRITE(6,72)P0M,P0B,P0CIRM,P0CIRB                                     MSDG167
   72 FORMAT(1X,19X,'P0M=',F10.4,5X, 'P0B=',F10.4,5X, 'P0CIRM=',F10.4,     MSDG168
     1 5X,'P0CIRB=',F10.4)                                                 MSDG169
                                                                           MSDG170
C  READ THE FLOW (DUMF) VS. PRESSURE (DUMP) DATA FOR OXYGEN.               MSDG171
C  THIS DATA IS ABSOLUTE PER THE CALIBRATIONS ESTABLISHED IN THIS           MSDG172
C  COMPUTER PROGRAM. THIS DATA WAS REDUCED BY HAND.                         MSDG173
C                                                                          MSDG174
      READ(5,15) (DUMF(I),DUMP(I),I=1,17)                                  MSDG175
      NTR=17                                                               MSDG176
      IOR=1                                                                MSDG177
C                                                                          MSDG178
C  FLOW VS. PRESSURE DATA IS FITTED TO A QUADRATIC EQN. BELOW               MSDG179
C                                                                          MSDG180
      CALL QUADFT(DUMF,DUMP,NTR,IOR,A,B,C,FIT)                             MSDG181
      FLOWA=A                                                              MSDG182
      FLOWB=B                                                              MSDG183
      FLOWC=C                                                              MSDG184
      WRITE(6,73)                                                          MSDG185
      DO 91 I=1,17                                                         MSDG186
      WRITE(6,74)DUMF(I),DUMP(I)                                           MSDG187
   91 CONTINUE                                                             MSDG188
      WRITE(6,66)                                                          MSDG189
      WRITE(6,363)I,FLOWA,FLOWB,FLOWC,FIT                                  MSDG190
  363 FORMAT(1X,'FOR TRANS. CAL.',I2,'FLOW(Y-AXIS) VS. PRESS.(X-AXIS)      MSDG191
     1  COEFS. ARE A=',E10.4,5X,'B=',E10.4,5X,'C=',E10.4,5X,'STDDEV=',     MSDG192
     2  E10.4/)                                                           MSDG193
   73 FORMAT(1H1,'FLOW O2 CC/MINUTE',5X,'PRESSURE IR-TORR'//)              MSDG194
   74 FORMAT(1X,4X,E10.4,11X,E10.4)                                        MSDG195
                                                                           MSDG196
C  READ ON THE THERMOCOUPLE GAUGE, OBSERVED PRESSURE (OXYGEN               MSDG197
C  CALIBRATION BASIS)  (DUMO) VS. ACTUAL PURE CO2 PRESSURE (DUMC)           MSDG198
C                                                                          MSDG199
      READ(5,15) (DUMO(I),DUMC(I),I=1,27)                                  MSDG200
      NTR=27                                                               MSDG201
      IOR=1                                                                MSDG202
C                                                                          MSDG203
C  FIT ABOVE DATA TO A QUADRATIC EQN. . HOWEVER, IN THIS PROGRAM            MSDG204
C  THIS DATA IS USED AS A LOOK-UP TABLE DUE TO POOR QUADR. FIT              MSDG205
C  OVER LARGE RANGE.                                                        MSDG206
C                                                                          MSDG207
      CALL QUADFT(DUMO,DUMC,NTR,IOR,A,B,C,FIT)                             MSDG208
      APCO2=A                                                              MSDG209
      BPCO2=B                                                              MSDG210
      CPCO2=C                                                              MSDG211
                                                                           MSDG212
```

```
      WRITE(6,75)                                                          MSDG213
   75 FORMAT(1H1,'PRESSURE OBSERVED O2',5X,'PRESSURE ACTUAL CO2',/,        MSDG214
     1  7X,'(TORR)',7X,5X,7X,'(TORR)'//)                                   MSDG215
      DO 92 I=1,27                                                         MSDG216
      WRITE(6,74) DUMO(I),DUMC(I)                                          MSDG217
   92 CONTINUE                                                             MSDG218
      WRITE(6,66)                                                          MSDG219
      WRITE(6,93) APCO2,BPCO2,CPCO2,FIT                                    MSDG220
C                                                                          MSDG221
C     READ OBSERVED PRESSURE (O2 BASIS) (DUMO) VS. ACTUAL PRESSURE         MSDG222
C     PURE WATER VAPOR PRESSURE (DUMH)                                     MSDG223
C                                                                          MSDG224
   93 FORMAT(1X,'APCO2=',E10.4,2X,'BPCO2=',E10.4,2X,'CPCO2=',E10.4,2X,     MSDG225
     1  'STDDEV=',E10.4)                                                   MSDG226
      READ(5,15) (DUMO(I),DUMH(I),I=1,29)                                  MSDG227
      NTR=29                                                               MSDG228
      IOR=1                                                                MSDG229
C                                                                          MSDG230
C     FIT DATA TO QUADRATIC. HOWEVER, DATA USED AS LOOK-UP TABLE           MSDG231
C                                                                          MSDG232
      CALL QUADFT(DUMO,DUMH,NTR,IOR,A,B,C,FIT)                             MSDG233
      APH2O=A                                                              MSDG234
      BPH2O=B                                                              MSDG235
      CPH2O=C                                                              MSDG236
      WRITE(6,76)                                                          MSDG237
   76 FORMAT(1H1,'PRESSURE OBSERVED O2',5X,'PRESSURE ACTUAL H2O',/,        MSDG238
     1  7X,'(TORR)',7X,5X,7X,'(TORR)'//)                                   MSDG239
      DO 94 I=1,29                                                         MSDG240
      WRITE(6,74) DUMO(I),DUMH(I)                                          MSDG241
   94 CONTINUE                                                             MSDG242
      WRITE(6,66)                                                          MSDG243
      WRITE(6,95) APH2O,BPH2O,CPH2O,FIT                                    MSDG244
   95 FORMAT(1X,'APH2O=',E10.4,2X,'BPH2O=',E10.4,2X,'CPH2O=',E10.4,2X,     MSDG245
     1  'STDDEV=',E10.4)                                                   MSDG246
C                                                                          MSDG247
CCC   THIS SECTION READS THE CALIBRATION TEMPERATURE READINGS BETWEEN      MSDG248
C                                                                          MSDG249
CCC   THE ABSOLUTE TEMP. CHEMICAL MELTING POINTS(T0),THE IRON-CONSTANTAN   MSDG250
C                                                                          MSDG251
CCC   HOT CHUCK THERMOCOUPLE,AND THE IR INDUSTIES INFRARED PYROMETER.      MSDG252
C                                                                          MSDG253
CCC   IT PERFORMS LINEAR REGRESSIONS TO CONVERT PYROMETER READINGS TO      MSDG254
C                                                                          MSDG255
CCC   ABSOLUTE TEMP. USING FUNCTION T0PYR . THE THERMOCOUPLE READINGS      MSDG256
C                                                                          MSDG257
CCC   LAVE BEEN CONVERTED FROM MVOLTS (CORRECTED FOR AIR TEMP.) TO         MSDG258
      TEMPERATURE USING A TABLE.                                           MSDG259
      READ(5,10) NT0                                                       MSDG260
      READ(5,15)  (T0CHEM(I),T0HCTC(I),I=1,NT0)                            MSDG261
C                                                                          MSDG262
      READ(5,10) NT1                                                       MSDG263
      READ(5,15)  (T1HCTC(I),T1PYR(I),I=1,NT1)                             MSDG264
C                                                                          MSDG265
                                                                           MSDG266
```

```
C
      WRITE(6,80)                                                       MSDG267
   80 FORMAT(1H1,50X,'TEMPERATURE CALIBRATION DATA'/1X,49X,30('-')//,    MSDG268
     1  1X,41X, 'ALL TEMPERATURES ARE IN DEG. C',//)                    MSDG269
      WRITE(6,82)NT0,NT1                                                MSDG270
   82 FORMAT(42X, 'NT IS THE NUMBER OF DATA POINTS TAKEN'///1X,11X,     MSDG271
     1 'NT0=',I2,24X,'NT1=',I2///1X)                                    MSDG272
      WRITE(6,84)                                                       MSDG273
   84 FORMAT(1X, 'CHEM MELTING',5X, 'HOT CHUCK',6X, 'HOT CHUCK')        MSDG274
      WRITE(6,86)                                                       MSDG275
   86 FORMAT(1X, 'POINT(DEG C)',4X, 'TEMPERATURE',4X,'TEMPERATURE',3X,  MSDG276
     1 'IR PYROMETER')                                                  MSDG277
      WRITE(6,88)                                                       MSDG278
   88 FORMAT(1X,1X,11('-'),2X,3(2X,11('-'),2X))                         MSDG279
C                                                                       MSDG280
C                                                                       MSDG281
C                                                                       MSDG282
      DO 100 KK=1,50                                                    MSDG283
C                                                                       MSDG284
   90 IF(KK.GT.NT0.AND.KK.GT.NT1)GO TO 101                              MSDG285
      WRITE(6,50)                                                       MSDG286
C                                                                       MSDG287
C                                                                       MSDG288
      DO 250 KKK=1,2                                                    MSDG289
C                                                                       MSDG290
      GO TO(255,256),KKK                                                MSDG291
C                                                                       MSDG292
  255 IF(KK.GT.NT0)GO TO 250                                            MSDG293
      WRITE(6,52)T0CHEM(KK),T0HCTC(KK)                                  MSDG294
      GO TO 250                                                         MSDG295
  256 IF(KK.GT.NT1)GO TO 250                                            MSDG296
  250 CONTINUE                                                          MSDG297
      WRITE(6,53)T1HCTC(KK),T1PYR(KK)                                   MSDG298
C                                                                       MSDG299
  100 CONTINUE                                                          MSDG300
  101 CONTINUE                                                          MSDG301
C                                                                       MSDG302
C  LINEAR REGRESSION ANALYSIS OF TEMPERATURE DATA                       MSDG303
                                                                        MSDG304
      CALL REGLNR(T0CHEM,T0HCTC,NT0,TM0,TB0,TFIT0)                      MSDG305
      CALL REGLNR(T1HCTC,T1PYR,NT1,TM1,TB1,TFIT1)                       MSDG306
C                                                                       MSDG307
      T0M= TM0*TM1                                                      MSDG308
      T0B= TM0*TB1 + TB0                                                MSDG309
C                                                                       MSDG310
C     WRITE(6,66)                                                       MSDG311
      WRITE(6,120)  TM0,TB0,TFIT0,TM1,TB1,TFIT1,T0M,T0B                 MSDG312
  120 FORMAT(1X,19X, 'SLOPE TM0=',F10.4,5X, 'INTERCEPT TB0=',F10.4,5X,  MSDG313
     1 'FIT OF LINE=',F10.4//1X,19X, 'SLOPE TM1=',F10.4,5X,'INTERCEPT TB MSDG314
     21=',F10.4,  5X, 'FIT OF LINE=',F10.4////1X,19X,'T0M=',F10.4,5X,   MSDG315
     3 'T0B=',F10.4)                                                    MSDG316
C                                                                       MSDG317
C     THIS SECTION READS EQUILIBRIUM VALUES SIMULTANEOUSLY OF CO2 AND O2MSDG318
                                                                        MSDG319
                                                                        MSDG320
```

```
C
C     FLOW, REACTOR PRESS.,REL. PERCENT TRANSMITTANCE, AND THE ZERO CO2      MSDG321
C     CONC. BASELINE TRANSMITTANCE.                                          MSDG322
C                                                                            MSDG323
C      THE CO2 AND O2 FLOWS ARE                                              MSDG324
C                                                                            MSDG325
C     CORRECTED FOR THE TYLAN H2 FLOW CONTROLLER USING TYLAN'S PUBLISHED     MSDG326
C     FACTORS (FUNTION FOCO2 AND FUNCTION FOO2). THE PRESS. READING IS       MSDG327
C                                                                            MSDG328
C     CONVERTED TO ACTUAL IR CELL PRESS. SUBRTNE PCBFND NEXT THE FLOW        MSDG329
C     % CO2 AND THE IR CELL PRESSURE ARE USED TO CALCULATE THE ACTUAL        MSDG330
C     CO2 CONC.(GM-MOLES/LITER) IN THE CELL WHICH IS FED WITH THE            MSDG331
C     ABSORBANCE = -LOG(TRANSMITTANCE) INTO THE LINEAR REGRESSION            MSDG332
C     SUBROUTINE. THIS RELATION IS USED TO OBTAIN CO2 CONC. FROM TRANS.      MSDG333
C     DATA. TRANSMITTANCE = REL. TRANS./BASELINE TRANS. . THE BEAM PATH      MSDG334
C     IN THE IR CELL WAS SET AT 6.4 METERS LONG.                             MSDG335
C                                                                            MSDG336
      DO 190 J=1,2                                                           MSDG337
C                                                                            MSDG338
C     CALIBRATIONS WERE DONE ON TWO DIFFERENT DAYS. J=1 IS THE DAY           MSDG339
C                                                                            MSDG340
C     WHEN THE PRIMARY EXPERIMENTS WERE DONE.                                MSDG341
C                                                                            MSDG342
      READ(5,10)  NCAL                                                       MSDG343
      READ(5,10)  NTRAN(NCAL)                                                MSDG344
      READ(5,15) BLINET                                                      MSDG345
C                                                                            MSDG346
C                                                                            MSDG347
  900 WRITE(6,140)                                                           MSDG348
      BLINET=BLINET + 0.07                                                   MSDG349
  140 FORMAT(1H1,45X, 'TRANSMITTANCE CALIBRATION DATA'/1X,44X,30('-')//)     MSDG350
C                                                                            MSDG351
      WRITE(6,145)  NTRAN(NCAL),BLINET                                       MSDG352
  145 FORMAT(1X///1X, 'THE NUMBER OF DATA POINTS TAKEN=',I2//1X,             MSDG353
     1 'THE BASELINE TRANSMITTANCE (ZERO CO2) =',F10.4////1X,                MSDG354
     2  'CONCENTRATION IS IN GRAMMOLES/LITER',//1X,'PRESSURE IS IN TORR'     MSDG355
     3  ,///)                                                               MSDG356
C                                                                            MSDG357
C                                                                            MSDG358
      WRITE(6,150)                                                           MSDG359
C     WRITE(6,151)                                                           MSDG360
C                                                                            MSDG361
  150 FORMAT(1X,'RAW FLOW CO2',1X,'RAW FLOW O2',1X,'RAW REACTR',3X,          MSDG362
     1 'RELATIVE',2X,5(2X,'ABSOLUTE',2X ),'TOTAL FLOW')                      MSDG363
C                                                                            MSDG364
  151 FORMAT(1X,1X,' CC/MINUTE',2X,' CC/MINUTE',2X,'PRES.-TORR',2X,          MSDG365
C                                                                            MSDG366
                                                                             MSDG367
                                                                             MSDG368
                                                                             MSDG369
                                                                             MSDG370
                                                                             MSDG371
                                                                             MSDG372
                                                                             MSDG373
                                                                             MSDG374
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1  'TRANSMITT.',2X,'    % CO2  ',2X,'CONC.  CO2',2X,'TRANSMITT.',2X,MSDG375
2  'ABSORBANCE',2X,' IR PRESS.',2X,' CC/MINUTE'/ 1X,9(2X,8('-'),2X) MSDG376
3  ,2X,8('-'))                                                      MSDG377
C                                                                   MSDG378
C   THIS SECTION READS THE RAW DATA THEN                            MSDG379
C                                                                   MSDG380
C  THIS SEGMENT CONVERTS ALL THE UNCALIBRATED DATA TO ABSOLUTE VALUESMSDG381
C                                                                   MSDG382
C  AND THEN USES THESE TO CALCULATE CO2 CONC.  ,  ABSORBANCE ,AND THEMSDG383
C                                                                   MSDG384
C  LINEAR RELATIONSHIP BETWEEN THESE VARIABLES.                     MSDG385
C                                                                   MSDG386
      NTR=NTRAN(NCAL)                                               MSDG387
      DO 30 I=1,NTR                                                 MSDG388
C                                                                   MSDG389
      READ(5,15)  FCO2,FO2,PRT,RELT                                 MSDG390
      RELT=RELT+0.07                                                MSDG391
      CO2PER(I) =  F0CO2(FCO2) / (F0CO2(FCO2) +F0O2(FO2))           MSDG392
      TRAN=(RELT) / (BLINET)                                        MSDG393
      ABSORB(I) =  -1.0* ALOG10(TRAN)                               MSDG394
      FCO2CB(NCAL,I) =F0CO2(FCO2)                                   MSDG395
      FO2CB(NCAL,I) =F0O2(FO2)                                      MSDG396
      PREM(NCAL,I) =PRT                                             MSDG397
      FCREM(NCAL,I) =FCO2                                           MSDG398
      FOREM(NCAL,I) =FO2                                            MSDG399
      RLTREM(NCAL,I) =RELT                                          MSDG400
C                                                                   MSDG401
C                                                                   MSDG402
      CO2PR(NCAL,I) =CO2PER(I)                                      MSDG403
      ABSRB(NCAL,I) =ABSORB(I)                                      MSDG404
      YYCO2=CO2PER(I)                                               MSDG405
      CALL PCBFND(PRT,YYCO2,DUMO,DUMC          ,PACTCB)             MSDG406
      CO2CON(I) =CO2PER(I) * (PACTCB/760.0) * (1.0/24.631)          MSDG407
      CO2CN(NCAL,I) =CO2CON(I)                                      MSDG408
      EQVPRT= (PACTCB-P0CIRB) /P0CIRM                               MSDG409
      PIRCB(NCAL,I) =PACTCB                                         MSDG410
      PRCTCB(NCAL,I) =P0RT(EQVPRT)                                  MSDG411
C                                                                   MSDG412
      DUMY(I) =FCO2CB(NCAL,I) +  FO2CB(NCAL,I)                      MSDG413
      DUMX(I) =PIRCB(NCAL,I)                                        MSDG414
30  WRITE(6,32 )  FCO2,FO2,  PRT,RELT,CO2PER(I) ,CO2CON(I) ,TRAN,ABSORB(I) MSDG415
     1   ,PIRCB(NCAL,I) ,DUMY(I)                                    MSDG416
32  FORMAT(1X,10(1X,E10.4,1X))                                      MSDG417
C                                                                   MSDG418
C                                                                   MSDG419
31  IOR=1                                                           MSDG420
C                                                                   MSDG421
C   LINEAR REGRESSION OF FLOW (DUMY) VS. PRESSURE (DUMX)  FOR THE   MSDG422
C   CALIBRATION DATA                                                MSDG423
C                                                                   MSDG424
      CALL REGLNR(DUMY,DUMX,NTR,CON0M,CON0B,CONFIT)                 MSDG425
      FLWA(NCAL) =CON0B                                             MSDG426
      FLWB(NCAL) =CON0M                                             MSDG427
      FLWC(NCAL) =0.0                                               MSDG428
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      FITT(NCAL) =CONFIT                                                    MSDG429
      WRITE(6,66)                                                           MSDG430
      WRITE(6,363)  NCAL,FLWA(NCAL),FLWB(NCAL),FLWC(NCAL),FITT(NCAL)        MSDG431
C                                                                           MSDG432
C     LINEAR REGRESSION OF CO2 CONCENTRATION VS. ABSORBANCE FOR THE         MSDG433
C     CALIBRATION DATA.                                                     MSDG434
C                                                                           MSDG435
      CALL REGLNR(CO2CON,ABSORB,NTR, CON0M,CON0B,CONFIT)                    MSDG436
      CONM(NCAL) =CON0M                                                     MSDG437
      CONB(NCAL) =CON0B                                                     MSDG438
      CONF(NCAL) =CONFIT                                                    MSDG439
      WRITE(6,160) CON0M,CON0B, CONFIT                                      MSDG440
C                                                                           MSDG441
  160 FORMAT(1X,'SLOPE CON0M=',E10.4,5X,'INTERCEPT CON0B=',E10.4,5X,        MSDG442
     1 'FIT OF LINE=',E10.4 )                                               MSDG443
  190 CONTINUE                                                              MSDG444
C                                                                           MSDG445
CC    THIS SECTION READS THE DATA FOR EACH RUN, CORRECTS IT VIA THE         MSDG446
C                                                                           MSDG447
CC    CALIBRATION FUNCTIONS, PERFORMS SEVERAL CALCULATIONS AND PRINTS       MSDG448
C                                                                           MSDG449
CC    OUT FINAL RESULTS IN CHART FORM.                                      MSDG450
C                                                                           MSDG451
C                                                                           MSDG452
C                                                                           MSDG453
C                                                                           MSDG454
C                                                                           MSDG455
      DO 500 I=1,10                                                         MSDG456
C                                                                           MSDG457
      READ(5,400) NRUNNO,  NDATA(NRUNNO),NOWAFS,POWLEV(NRUNNO),FO2,        MSDG458
     1  BLINE(NRUNNO),WTLOSS(NRUNNO)                                        MSDG459
C                                                                           MSDG460
  400 FORMAT(I2,1X,I2,1X,I2,2X,4F10.4)                                      MSDG461
      II=NRUNNO                                                             MSDG462
      BLINE(II)=BLINE(II) +0.07                                             MSDG463
      WRITE(6,640) NRUNNO,NDATA(II),NOWAFS,POWLEV(II),FO2,BLINE(II)         MSDG464
  640 FORMAT(1H1, 'RUN NUMBER' ,3X,I2/1X, 'NO. DATA POINTS' ,3X,I2/1X,      MSDG465
     1'NUMBER OF WAFERS' ,3X,I2/1X, 'POWER LEVEL RF WATTS' ,3X,F10.4/1X,    MSDG466
     2 'O2 FEED RATE',3X,F10.6,3X,'CC/MINUTE'/1X, 'BASELINE',               MSDG467
     3 ' TRANSMITTANCE',3X,F10.4)                                           MSDG468
  650 FORMAT(1H0///7X, '    TIME      ' ,11X, 'RELATIVE TRANSMITTANCE' ,    MSDG469
     1 4X, 'REACTOR PRESSURE METER' ,10X, 'PYROMETER METER' )                MSDG470
  652 FORMAT(9X,2X,'(MINUTES)',2X,37X,8X,'(TORR)'18X,'(DEG. CELSIUS)')      MSDG471
      WRITE(6,650)                                                          MSDG472
      WRITE(6,652)                                                          MSDG473
      WRITE(6,660)                                                          MSDG474
  660 FORMAT(7X,15('-'),10X,24('-'),2X,24('-'),10X,17('-'))                 MSDG475
C                                                                           MSDG476
      CON0M=CONM(1)                                                         MSDG477
      CON0B=CONB(1)                                                         MSDG478
      ND=NDATA(II)                                                          MSDG479
      NJ=1                                                                  MSDG480
      CDLTOT(II,1)=0.0                                                      MSDG481
      DO 600 K=1,ND                                                         MSDG482
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C                                                                       MSDG483
      READ(5,15)  TIME(II,K),RELT,PRT,TPYR                              MSDG484
      RELT=RELT +0.07                                                   MSDG485
C                                                                       MSDG486
C                                                                       MSDG487
C                                                                       MSDG488
      TPYROM(II,K)=T0PYR(TPYR)                                          MSDG489
      IF(TPYROM(II,K)  .LT.  100.0) TPYROM(II,K)=0.0                    MSDG490
      ABSOB=-1.0*ALOG10((RELT)/(BLINE(II)))                             MSDG491
      ABSB(II,K)=ABSOB                                                  MSDG492
      POB1(II,K)=PRT                                                    MSDG493
      DUMX(K)=TIME(II,K)                                                MSDG494
      TRANS(II,K)=(RELT)/(BLINE(II))                                    MSDG495
  621 CONTINUE                                                          MSDG496
C                                                                       MSDG497
C                                                                       MSDG498
      WRITE(6,670)  TIME(II,K),RELT,PRT,TPYR                            MSDG499
  670 FORMAT(1X,   1X,  6X ,F10.4,5X,11X,5X,F10.4,7X,2X,6X,F9.4,23X,F10.4) MSDG500
  600 CONTINUE                                                          MSDG501
      READ(5,15)  COPRA(II),COPRB(II),COPRY(II)                         MSDG502
      READ(5,15)  COTMPA(II),COTMPB(II),COTMPY(II)                      MSDG503
      READ(5,15)  COABA(II),COABB(II),COABY(II)                         MSDG504
      FACTOR=1.0                                                        MSDG505
C                                                                       MSDG506
C   THIS NEXT SECTION SENDS THE DATA THROUGH THE FULL SET OF            MSDG507
C   CALCULATIONS ONCE, THEN COMPARES THE CARBON DIOXIDE LEAVING         MSDG508
C   THE SYSTEM WITH THE ACTUAL CARBON LOST FROM THE POLYMER AND DOES    MSDG509
C   A SECOND SET SET OF CALCULATIONS USING FLOWS NORMALIZED BY THE      MSDG510
C   CARBON MATERIAL BALANCE. (FACTOR)                                   MSDG511
C                                                                       MSDG512
  731 CDLTOT(II,1)=0.0                                                  MSDG513
      DO 680 K=1,ND                                                     MSDG514
      PRT=POB1(II,K)                                                    MSDG515
      ABSOB=ABSB(II,K)                                                  MSDG516
      CO2C2=CDCON(ABSOB)                                                MSDG517
      IF(CO2C2 .LT. 0.0) CO2C2=0.0                                      MSDG518
      CALL PFIND(PRT,CO2C2,DUMO,DUMC,DUMH                ,PACT2)       MSDG519
      PIR(II,K)=PACT2                                                   MSDG520
      YCO2(II,K)=CO2C2*760.0*24.631/PACT2                               MSDG521
      CO2C(II,K)=CO2C2                                                  MSDG522
      FLOW2(II,K)=FLOW(PACT2)                                           MSDG523
      FLOW2(II,K)=FLOW2(II,K)/FACTOR                                    MSDG524
      CDLSPM(II,K)=CO2C(II,K)*0.001*FLOW2(II,K)*(760.0/PIR(II,K))*44.0  MSDG525
      IF(K .EQ. 1)  GO TO 685                                           MSDG526
      CDLOSS(II,K)= CDLSPM(II,K)*(TIME(II,K)-TIME(II,K-1))              MSDG527
      IF(CDLOSS(II,K)  .LE. 0.0) CDLOSS(II,K)=0.0                       MSDG528
      GO TO 682                                                         MSDG529
  685 CDLOSS(II,1)= CDLSPM(II,1)*1.0                                    MSDG530
      IF(CDLOSS(II,1)  .LE. 0.0) CDLOSS(II,1)=0.0                       MSDG531
      CDLTOT(II,1)=CDLOSS(II,1)                                         MSDG532
      CDL(1)=CDLTOT(II,1)                                               MSDG533
      GO TO 683                                                         MSDG534
  682 CDLTOT(II,K)= CDLTOT(II,K-1)  +  CDLOSS(II,K)                     MSDG535
      CDL(K)=CDLTOT(II,K)                                               MSDG536
```

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C
C   THE SYSTEM VOLUME IS ESTIMATED AT 20.90 LITERS                          MSDG537
C                                                                           MSDG538
  683 DCO2DT(II,K)=CON0M*(COABA(II)*(+COABB(II))*EXP(-COABB(II)*TIME(II,    MSDG539
     1  K)))/20.90                                                          MSDG540
      VT=20.90                                                             MSDG541
C                                                                          MSDG542
C   THE SYSTEM VOLUME IS ESTIMATED AT 20.90 LITERS                         MSDG543
C                                                                          MSDG544
C   THE REACTOR VOLUME IS 12.0 LITERS. HOW MUCH OF THIS IS                 MSDG545
C   EFFECTIVE VOLUME IS UNKNOWN                                            MSDG546
C                                                                          MSDG547
      R(II,K)=(0.001*FLOW2(II,K)*(760.0/PIR(II,K))     *CO2C(II,K) + VT*   MSDG548
     1  DCO2DT(II,K))/12.0                                                 MSDG549
      YO2(II,K)=1.0-1.8*YCO2(II,K)                                         MSDG550
      IF(YO2(II,K) .LT. 0.0)YO2(II,K)=0.0                                  MSDG551
      DO2DT(II,K)=(-0.001*FLOW2(II,K)*YO2(II,K)/24.631                     MSDG552
     1  +0.001*F002(FO2)/24.631-(7.0/5.0)*12.*R(II,K))/VT                  MSDG553
  680 CONTINUE                                                             MSDG554
      IOR=2                                                                MSDG555
C                                                                          MSDG556
C   FIT THE TOTAL CO2 LOSS DATA IN GRAMS VS. TIME TO A QUADRATIC           MSDG557
C   EQN.                                                                   MSDG558
C                                                                          MSDG559
      CALL QUADFT(CDL,DUMX,ND,IOR,A,B,C,FIT)                               MSDG560
      ND=NDATA(II)                                                         MSDG561
      F2(II)=F002(FO2)                                                     MSDG562
      COTOTA(II)=A                                                         MSDG563
      COTOTB(II)=B                                                         MSDG564
      COTOTC(II)=C                                                         MSDG565
      WRITE(6,640) II,NDATA(II),NOWAFS,POWLEV(II),F2(II), BLINE(II)        MSDG566
C                                                                          MSDG567
      WRITE(6,700)FACTOR                                                   MSDG568
  700 FORMAT(1X,//1X,'THE DATA ON THIS PAGE WAS REDUCED USING THE',        MSDG569
     1 'CALIBRATION RELATIONS DEVELOPED EARLIER IN THIS PROGRAM',/1X,      MSDG570
     2  'FLOW NORMALIZATION FACTOR WAS,',1X,F10.5/)                       MSDG571
      WRITE(6,710) WTLOSS(II),CDLTOT(II,ND)                                MSDG572
  710 FORMAT(1X, 'THE MEASURED WT. LOSS IS' ,3X,F10.4,3X,'GRAMS', 5X ,     MSDG573
     1 'THE CO2 LOSS CALCULATED FROM TRANSMITTANCE DATA IS',3X,F10.4,3X,   MSDG574
     2 'GRAMS' //)                                                         MSDG575
      WRITE(6,720)                                                         MSDG576
      WRITE(6,721)                                                         MSDG577
C                                                                          MSDG578
C   THERE ARE TWELVE SPACES PER COLUMN; 10 DIGITS AND ONE                  MSDG579
C   SPACE ON EACH SIDE IN THE FORMATS BELOW.                               MSDG580
C                                                                          MSDG581
                                                                           MSDG582
  720 FORMAT(1X,24X, 1X,'TRANSMIT-',4X,'RXN-RATE',5X,'IR CELL',4X,         MSDG583
     1  'CO2 MOLE',4X,'CO2 LOSS',3X,'  TOTAL ',6X,'WAFER',6X,'D(O2)/DT')   MSDG584
  721 FORMAT(1X,4X,'TIME',5X,'ABSORBANCE',4X,'-TANCE',4X,'GRAMMOLES/',     MSDG585
     1  3X,'PRESSURE',4X,'FRACTION',3X,'  GRAMS  ',3X,'CO2 LOSS'  ,2X,     MSDG586
     2 'TEMPERATURE',1X,1X,'GRAMMOLES/')                                   MSDG587
      WRITE(6,735)                                                         MSDG588
  735 FORMAT(1X,1X,'(MINUTES)',1X,24X,2X,'LITER-MIN.',                     MSDG589
     !  1X,3X,'(TORR)',16X  ,'PER MINUTE',1X,1X,'  (GRAMS) ',              MSDG590
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     2  1X,'(DEGREES C)',1X,1X,'LITER-MIN.')                                  MSDG591
C                                                                             MSDG592
C                                                                             MSDG593
      WRITE(6,722)                                                            MSDG594
  722 FORMAT(1X,1X,10('-'),1X,9(1X,10('-'),1X)/)                              MSDG595
  725 FORMAT(1X,1X,E10.4,1X,9(1X,E10.4,1X))                                   MSDG596
      DO 502 J=1,ND                                                           MSDG597
      WRITE(6,725) TIME(II,J),ABSB(II,J),TRANS(II,J),R(II,J),PIR(II,J),       MSDG598
     1    YCO2(II,J),CDLSPM(II,J),CDLTOT(II,J),TPYROM(II,J),DO2DT(II,J)       MSDG599
  502 CONTINUE                                                                MSDG600
      WRITE(6,66)                                                             MSDG601
      WRITE(6,602)                                                            MSDG602
      WRITE(6,603) II,COABA(II), COABB(II),COABY(II)                          MSDG603
  603 FORMAT(1X,'FOR RUN NO.',I2,3X,'THE COEFICIENT VALUES ARE A=',E10.4MSDG604
     1  ,5X,'B=',E10.4,5X,'Y0=',E10.4/)                                       MSDG605
  602 FORMAT(1X,'ABSORBANCE')                                                 MSDG606
      WRITE(6,604)                                                            MSDG607
  604 FORMAT(1X,'PRESSURE IR CELL')                                           MSDG608
      WRITE(6,603) II,COPRA(II),COPRB(II),COPRY(II)                           MSDG609
      WRITE(6,606)                                                            MSDG610
  606 FORMAT(1X,'TEMPERATURE')                                                MSDG611
      WRITE(6,603) II,COTMPA(II),COTMPB(II),COTMPY(II)                        MSDG612
      WRITE(6,607)     COTOTA(II),COTOTB(II),COTOTC(II)                       MSDG613
  607 FORMAT(1X,'BEST QUADRATIC FIT OF THE TOTAL CO2 LOSS(GRAMS)  WITH        MSDG614
     1 TIME GIVES COEFS. A=',E10.4,5X,'B=',E10.4,5X,'C=',E10.4)               MSDG615
      FACTOR=((12.0/44.0)*CDLTOT(II,ND))/((12.0/13.6)*WTLOSS(II))             MSDG616
      IF(ABS(FACTOR) .LT. 0.01)GO TO 500                                      MSDG617
      IF(ABS(FACTOR-1.0) .LE. 0.01)GO TO 500                                  MSDG618
      GO TO 731                                                               MSDG619
  500 CONTINUE                                                                MSDG620
      XD=8.5                                                                  MSDG621
      YD=11.0                                                                 MSDG622
C                                                                             MSDG623
C   THE INITIAL COMMENT CARD READ IS THE SCALE TYPE( LINEAR,LOG-LOG,ETC)      MSDG624
C   THE FIRST CARD READ AFTER THIS GIVES THE X-AXIS TITLE IN COL. 1-20        MSDG625
C   THE SECOND CARD GIVES THE Y-AXIS TITLE IN COLUMNS 1-20                    MSDG626
C   THE THIRD TO TENTH CARDS ARE COMMENTS TO GO UNDER THE PLOT.               MSDG627
C   UNLESS ALL 8 COMMENT CARDS ARE USED, THE LAST CARD AFTER THE              MSDG628
C   COMMENTS MUST BE AN END CARD, 'END ' IN COL. 1-4                          MSDG629
      READ(5,172) COMNT(240)                                                  MSDG630
  172 FORMAT(A4)                                                              MSDG631
C                                                                             MSDG632
C   IR CELL PRESSURE VS. TIME, NEXT IS WAFER TEMP. VS. TIME, THEN             MSDG633
C   ABSORBANCE VS. TIME, CO2 LOSS/MINUTE VS. TIME, CO2 LOSS TOTAL VS.         MSDG634
C   TIME                                                                      MSDG635
C                                                                             MSDG636
      WRITE(6,372)                                                            MSDG637
      K=1                                                                     MSDG638
      IFRAME=0                                                                MSDG639
  300 LC=-1                                                                   MSDG640
      COMNT(239)=BLANK                                                        MSDG641
      CALL RDPLOT(COMNT,NCT)                                                  MSDG642
      DO 305 II=1,10                                                          MSDG643
      ITMP=0                                                                  MSDG644
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      KTINF=0                                                          MSDG645
      IF(II.EQ.6.OR.II.EQ.7.OR.II.EQ.8.OR.II.EQ.10)GO TO 305           MSDG646
      ND=NDATA(II)                                                     MSDG647
      IF(II .EQ. 2)ND=17                                               MSDG648
      DO 312 I=1,ND                                                    MSDG649
      GO TO (315,320,325,330,335,336,337),K                            MSDG650
  315 YPLOT(I)=PIR(II,I)                                               MSDG651
      YF=2.20                                                          MSDG652
      YS=0.20                                                          MSDG653
      GO TO 310                                                        MSDG654
  320 YPLOT(I)= TPYROM(II,I)                                           MSDG655
      COEFA=COTMPA(II)                                                 MSDG656
      COEFB=COTMPB(II)                                                 MSDG657
      COEFY0=COTMPY(II)                                                MSDG658
      YF=0.0                                                           MSDG659
      YS=40.0                                                          MSDG660
      GO TO 310                                                        MSDG661
  325 YPLOT(I)=ABSB(II,I)                                              MSDG662
      COEFA=COABA(II)                                                  MSDG663
      COEFB=COABB(II)                                                  MSDG664
      COEFY0=COABY(II)                                                 MSDG665
      YF=0.0                                                           MSDG666
      YS=2.5E-02                                                       MSDG667
      GO TO 310                                                        MSDG668
  330 YPLOT(I)=CDLSPM(II,I)                                            MSDG669
      YF=0.00                                                          MSDG670
      YS=0.006                                                         MSDG671
      GO TO 310                                                        MSDG672
  335 YPLOT(I)=CDLTOT(II,I)                                            MSDG673
      YF=0.00                                                          MSDG674
      YS=0.13                                                          MSDG675
  310 XPLOT(I)=TIME(II,I)                                              MSDG676
      XF=0.00                                                          MSDG677
      XS=7.00                                                          MSDG678
      GO TO 312                                                        MSDG679
  336 CONTINUE                                                         MSDG680
      IF(II .EQ. 2)GO TO 305                                           MSDG681
      IF(I .EQ. 1)GO TO 332                                            MSDG682
      IF(TPYROM(II,I) .GT. 100.0 .AND. TPYROM(II,I-1) .LT. 100.0       MSDG683
     1  )ITMP=I-1                                                      MSDG684
  332 CONTINUE                                                         MSDG685
      IF(ITMP .EQ. 0)GO TO 312                                         MSDG686
      YPLOT(I-ITMP)= ALOG(R(II,I))                                     MSDG687
      XPLOT(I-ITMP)=1.0/(TPYROM(II,I) + 273.0)                         MSDG688
      XF=0.0                                                           MSDG689
      XS=0.5E-03                                                       MSDG690
      YF=-12.0                                                         MSDG691
      YS=2.0                                                           MSDG692
      GO TO 312                                                        MSDG693
  337 CONTINUE                                                         MSDG694
      IF(II .EQ. 2)GO TO 305                                           MSDG695
      IF(KTINF .EQ. 1)GO TO 339                                        MSDG696
      IF(I .EQ. 1)GO TO 338                                            MSDG697
      IF(TPYROM(II,I) .GT. 100.0.AND. TPYROM(II,I-1) .LT. 100.0        MSDG698
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   !  )ITMP=I-1                                                          MSDG699
338 CONTINUE                                                             MSDG700
    IF(ITMP .EQ. 0)GO TO 312                                             MSDG701
    ITP=ITMP + 1                                                         MSDG702
    KTFBES =1                                                            MSDG703
    DO 308 KTF=1,20                                                      MSDG704
    TINF=TPYROM(II,ND)  + FLOAT(KTF)                                     MSDG705
    DO 346 LL=ITP,ND                                                     MSDG706
    YPLOT(LL-ITMP)= ALOG(TINF-TPYROM(II,LL))                             MSDG707
346 XPLOT(LL-ITMP)=TIME(II,LL)                                           MSDG708
    NPNTS=ND-ITMP                                                        MSDG709
    CALL REGLNR(YPLOT,XPLOT,NPNTS,TSLOP,TINTCP ,FIT)                     MSDG710
    FITTMP(KTF)= ABS(FIT)                                                MSDG711
    IF(KTF .GE. 2)GO TO 309                                              MSDG712
    FITBES =ABS(FITTMP(1))                                               MSDG713
309 CONTINUE                                                             MSDG714
308 IF(ABS(FITTMP(KTF)) .GT. FITBES )KTFBES =KTF                         MSDG715
    KTINF=1                                                              MSDG716
    TINF=TPYROM(II,ND)  + FLOAT(KTFBES )                                 MSDG717
    WRITE(6,311)TINF,FITBES                                              MSDG718
311 FORMAT(1X,//1X,'T(INFINITY)=',F10.4,3X,'FITCOEF=',E10.4,3X)          MSDG719
339 YPLOT(I-ITMP)= ALOG(TINF-TPYROM(II,I))                               MSDG720
    XPLOT(I-ITMP)=TIME(II,I)                                             MSDG721
    GO TO 312                                                            MSDG722
312 CONTINUE                                                             MSDG723
    NDREAL=ND                                                            MSDG724
    IF(K .EQ. 6 .OR. K .EQ. 7)ND=ND-ITMP                                 MSDG725
    NDTMP=ND                                                             MSDG726
    IF(II .GE. 2) LC=77                                                  MSDG727
    IF(LC .EQ. 77)GO TO 316                                              MSDG728
    IFRAME=IFRAME+1                                                      MSDG729
    IF(IFRAME .EQ. 1)GO TO 316                                           MSDG730
    IF(MOD(IFRAME,2) .EQ. 0) GO TO 317                                   MSDG731
    CALL PLOT(0,-(YD+1.0),-3)                                            MSDG732
    GO TO 316                                                            MSDG733
317 CALL PLOT(-(XD+2.0),YD+1.0,-3)                                       MSDG734
316 CALL GENPLT(XPLOT,YPLOT, ND,LC,COMNT, NCT,XS,XF,YS,YF,XD,YD)         MSDG735
    ND=NDREAL                                                            MSDG736
    IF(K .NE. 6)GO TO 321                                                MSDG737
    CALL REGLNR(YPLOT,XPLOT,                                             MSDG738
   1  NDTMP,SLO,YINT,FITE)                                               MSDG739
    EACT(II)=1.986*(-SLO)                                                MSDG740
    FREQF(II)= EXP(YINT)                                                 MSDG741
    WRITE(6,324)II,EACT(II),FREQF(II)                                    MSDG742
324 FORMAT(1X,//1X,'THE ACTIVATION ENERGY FOR RUN',I2,'=',E10.4,         MSDG743
   1  'CALORIES',3X,'THE FREQUENCY FACTOR=',E10.4)                       MSDG744
    DIV=3.0E-03/90.0                                                     MSDG745
    TDIV=DIV                                                             MSDG746
    DO 327 I=1,90                                                        MSDG747
    YPLOT(I)=SLO*TDIV + YINT                                             MSDG748
    XPLOT(I)=TDIV                                                        MSDG749
327 TDIV=TDIV + DIV                                                      MSDG750
    GO TO 307                                                            MSDG751
321 CONTINUE                                                             MSDG752
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      IF(K .NE. 7)GO TO 322                                              MSDG753
      CALL REGLNR(YPLOT,XPLOT,NDTMP,TSLOP,TINTCP,FIT)                    MSDG754
      HEATCO(II)   =-TSLOP*0.01957                                       MSDG755
      TMPZER(II)  =-EXP(TINTCP ) + TINF                                  MSDG756
      WRITE(6,341)II,HEATCO(II)   ,TMPZER(II)                            MSDG757
  341 FORMAT(1X,//1X,'THE HEAT TRANSFER COEFFICIENT, H, FOR RUN',        MSDG758
     1     1X,I2,1X,'=',E10.4,'CALORIES/CM**2-MIN-DEG K', /1X,           MSDG759
     2  'AND THE TIME(0) TEMPERATURE=',E10.4,'DEGREES C')                MSDG760
      DIV=TIME(II,ND)/90.0                                               MSDG761
      TDIV=DIV                                                           MSDG762
      DO 343 I=1,90                                                      MSDG763
      YPLOT(I)=TSLOP*TDIV + TINTCP                                       MSDG764
      XPLOT(I)=TDIV                                                      MSDG765
  343 TDIV=TDIV + DIV                                                    MSDG766
      GO TO 307                                                          MSDG767
  322 CONTINUE                                                           MSDG768
      IF(K .EQ. 1 .OR. K .EQ. 4)GO TO 355                                MSDG769
      DIV=TIME(II,ND)/90.0                                               MSDG770
      TDIV=DIV                                                           MSDG771
      IF(K .EQ. 5)GO TO 303                                              MSDG772
      DO 318 I=1,90                                                      MSDG773
      YPLOT(I)=COEFA*(1.0-EXP(-COEFB*TDIV)) +COEFY0                      MSDG774
      XPLOT(I)=TDIV                                                      MSDG775
  318 TDIV=TDIV+DIV                                                      MSDG776
      GO TO 307                                                          MSDG777
  303 DO 313 I=1,90                                                      MSDG778
      YPLOT(I)=COTOTA(II)+COTOTB(II)*TDIV+COTOTC(II)*TDIV**2.0           MSDG779
      XPLOT(I)=TDIV                                                      MSDG780
      TDIV=TDIV+DIV                                                      MSDG781
  313 CONTINUE                                                           MSDG782
  307 CONTINUE                                                           MSDG783
      NDIV=90                                                            MSDG784
  355 IF(K .EQ. 1 .OR. K .EQ. 4) NDIV=ND                                 MSDG785
      LC=77                                                              MSDG786
      COMNT(239)=FLIP                                                    MSDG787
      CALL GENPLT(XPLOT,YPLOT,NDIV,LC,COMNT,NCT,XS,XF,YS,YF,XD,YD)       MSDG788
  305 CONTINUE                                                           MSDG789
      K=K+1                                                              MSDG790
      IF(K .LE. 7)  GO TO 300                                            MSDG791
C                                                                        MSDG792
C   THIS SECTION READS AXES AND COMMENT CARDS FOR TWO PLOTS BASED ON THEMSDG793
C   CALIBRATION DATA .  THE FIRST IS TOTAL FLOW(CC/MIN.) VS. PRESSURE   MSDG794
C   IN THE IR CELL,AND THE SECOND PLOT ISCO2 CONCENTRATION VS. ABSORB-  MSDG795
C   ANCE.                                                                MSDG796
C                                                                        MSDG797
      K=1                                                                MSDG798
  340 LC=-1                                                              MSDG799
      CALL RDPLOT(COMNT,NCT)                                             MSDG800
      COMNT(239)=BLANK                                                   MSDG801
      DO 360 II=1,3                                                      MSDG802
      IF(K .EQ. 2 .AND. II .EQ. 3)GO TO 360                              MSDG803
      NTR=NTRAN(II)                                                      MSDG804
      IF(II .EQ. 3)NTR=17                                                MSDG805
      DO 350 I=1,NTR                                                     MSDG806
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C   TEMPERATURE AND PRESSURE.                                                MSDG861
C                                                                            MSDG862
      WRITE(6,372)                                                           MSDG863
  372 FORMAT(1H1,1X)                                                         MSDG864
      WRITE(6,370)                                                           MSDG865
  370 FORMAT(1X,2('PYROMETER READING',5X,'REAL TEMP.(DEG C)',5X))            MSDG866
      TEMP=95.0                                                              MSDG867
      DO 365 I=1,25                                                          MSDG868
      TEMP=TEMP+5.0                                                          MSDG869
      RLTEMP=T0M*TEMP+T0B                                                    MSDG870
      TMP=TEMP+130.0                                                         MSDG871
      RLTMP=T0M*TMP+T0B                                                      MSDG872
      WRITE(6,375)TEMP,RLTEMP,TMP,RLTMP                                      MSDG873
  375 FORMAT(1X,2(3X,E10.4,12X,E10.4,9X))                                    MSDG874
  365 CONTINUE                                                               MSDG875
      PRESS=1.9                                                              MSDG876
      WRITE(6,385)                                                           MSDG877
  385 FORMAT(1X,2('REACTOR METER',5X,'REAL RXTR PRESS.',5X,                  MSDG878
     1   'REAL IR PRESS.',5X))                                               MSDG879
      DO 380 I=1,35                                                          MSDG880
      PRESS=PRESS+0.1                                                        MSDG881
      RLRCPR=P0M*PRESS+P0B                                                   MSDG882
      RLIRPR=P0CIRM*PRESS+P0CIRB                                             MSDG883
      PRS=PRESS+3.6                                                          MSDG884
      RLRCPS=P0M*PRS+P0B                                                     MSDG885
      RLIRPS=P0CIRM*PRS+P0CIRB                                               MSDG886
      WRITE(6,390)PRESS,RLRCPR,RLIRPR,PRS,RLRCPS,RLIRPS                      MSDG887
  390 FORMAT(1X,2(1X,E10.4,10X,E10.4,10X,E10.4,5X))                          MSDG888
  380 CONTINUE                                                               MSDG889
  391 CONTINUE                                                               MSDG890
      END                                                                    MSDG891
      SUBROUTINE PCBFND(PRT,YYCO2,DUMO2,DUMCO2      ,PACTCB)                 PCBF  1
      COMMON P0M,P0B,P0CIRM,P0CIRB,T0M,T0B,CON0M,CON0B                       PCBF  2
      COMMON FLOWA,FLOWB,FLOWC                                               PCBF  3
      DIMENSION DUMO2(40),DUMCO2(40),DUMH2O(40)                              PCBF  4
      PACTCB=0.2*PRT                                                         PCBF  5
   10 PACTC2=YYCO2*PACTCB                                                    PCBF  6
      PACTO2=PACTCB-PACTC2                                                   PCBF  7
      DO 20 I=1,27                                                           PCBF  8
      IF(DUMCO2(I) .EQ. PACTC2)GO TO 40                                      PCBF  9
      IF(DUMCO2(I) .GT. PACTC2)GO TO 30                                      PCBF 10
   20 CONTINUE                                                               PCBF 11
   30 IF(I .EQ. 1)POBCO2=0.0                                                 PCBF 12
      IF(I .EQ. 1)GO TO 50                                                   PCBF 13
      FRACT=(PACTC2-DUMCO2(I-1))/(DUMCO2(I)-DUMCO2(I-1))                     PCBF 14
      POBCO2=DUMO2(I-1)  +  FRACT*(DUMO2(I)-DUMO2(I-1))                      PCBF 15
      GO TO 50                                                               PCBF 16
   40 POBCO2=DUMO2(I)                                                        PCBF 17
   50 CONTINUE                                                               PCBF 18
      POBTST=(PACTO2+POBCO2-P0CIRB)/P0CIRM                                   PCBF 19
      APROCH=(PRT-POBTST)/PRT                                                PCBF 20
      IF(ABS(APROCH) .LT. 0.002)  GO TO 100                                  PCBF 21
      PACTCB=(1.0+0.2*APROCH)*PACTCB                                         PCBF 22
      GO TO 10                                                               PCBF 23
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  100 CONTINUE                                                          PCBF 24
      RETURN                                                            PCBF 25
      END                                                               PCBF 26
      SUBROUTINE PFIND(PRT,CO2C2,DUMO2,DUMCO2,DUMH2O,PACT2)             PFND  1
      COMMON P0M,P0B,P0CIRM,P0CIRB,T0M,T0B,CON0M,CON0B                  PFND  2
      COMMON FLOWA,FLOWB,FLOWC                                          PFND  3
      DIMENSION DUMO2(40),DUMCO2(40),DUMH2O(40)                         PFND  4
      PACT2=0.2*PRT                                                     PFND  5
   10 YCO22=CO2C2*760.0*20.397/PACT2                                    PFND  6
      IF(YCO22 .LT. 0.0)YCO22=0.0                                       PFND  7
      IF(YCO22 .GT. 0.56)  GO TO 20                                     PFND  8
      GO TO 30                                                          PFND  9
   20 PACT2=1.05*PACT2                                                  PFND 10
      GO TO 10                                                          PFND 11
   30 YH2O2=0.8*YCO22                                                   PFND 12
      YO22=1.0-1.8*YCO22                                                PFND 13
      PACTC2=YCO22*PACT2                                                PFND 14
      PACTHO=YH2O2*PACT2                                                PFND 15
      PACTO2=YO22*PACT2                                                 PFND 16
      DO 40 I=1,27                                                      PFND 17
      IF(DUMCO2(1)  .GT.  PACTC2)GO TO 65                               PFND 18
      IF(DUMCO2(I)  .EQ.  PACTC2)GO TO 60                               PFND 19
      IF(DUMCO2(I)  .GT.  PACTC2)GO TO 50                               PFND 20
   40 CONTINUE                                                          PFND 21
   50 FRACT=(PACTC2-DUMCO2(I-1))/(DUMCO2(I)-DUMCO2(I-1))                PFND 22
      POBCO2=DUMO2(I-1)  +  FRACT*(DUMO2(I)-DUMO2(I-1))                 PFND 23
      GO TO 70                                                          PFND 24
   60 POBCO2=DUMO2(I)                                                   PFND 25
      GO TO 70                                                          PFND 26
   65 POBCO2=0.0                                                        PFND 27
   70 DO 75 I=1,29                                                      PFND 28
      IF(DUMH2O(1)  .GT.  PACTHO)GO TO 92                               PFND 29
      IF(DUMH2O(I)  .EQ.  PACTHO)GO TO 90                               PFND 30
      IF(DUMH2O(I)  .GT.  PACTHO)GO TO 80                               PFND 31
   75 CONTINUE                                                          PFND 32
   80 FRACT=(PACTHO-DUMH2O(I-1))/(DUMH2O(I)-DUMH2O(I-1))                PFND 33
      POBH2O=DUMO2(I-1)  +  FRACT*(DUMO2(I)-DUMO2(I-1))                 PFND 34
      GO TO 95                                                          PFND 35
   90 POBH2O=DUMO2(I)                                                   PFND 36
      GO TO 95                                                          PFND 37
   92 POBH2O=0.0                                                        PFND 38
   95 POBTST=(PACTO2+POBCO2+POBH2O-P0CIRB)/P0CIRM                       PFND 39
      APROCH=(PRT-POBTST)/PRT                                           PFND 40
      IF(ABS(APROCH)  .LT.  0.002)  GO TO 100                           PFND 41
      PACT2=(1.0+0.2*APROCH)*PACT2                                      PFND 42
      GO TO 10                                                          PFND 43
  100 CONTINUE                                                          PFND 44
      RETURN                                                            PFND 45
      END                                                               PFND 46
      FUNCTION CDCON(ABSOB)                                             CDCN  1
      COMMON P0M,P0B,P0CIRM,P0CIRB,T0M,T0B,CON0M,CON0B                  CDCN  2
C                                                                       CDCN  3
   10 CDCON=CON0M*ABSOB+ CON0B                                          CDCN  4
      RETURN                                                            CDCN  5
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      END                                                                CDCN  6
      FUNCTION FLOW(PRES)                                                FLOW  1
      COMMON P0M,P0B,P0CIRM,P0CIRB,T0M,T0B,CON0M,CON0B                   FLOW  2
      COMMON FLOWA,FLOWB,FLOWC                                           FLOW  3
      FLOW=FLOWA+ FLOWB*PRES+ FLOWC*PRES**2.0                            FLOW  4
      RETURN                                                             FLOW  5
      END                                                                FLOW  6
      SUBROUTINE QUADFT(YQ,XQ,NDP,IORIGN, A, B, C,FIT)                   QDFT  1
      DIMENSION YQ(40),XQ(40),AA(10),SIG(40)                             QDFT  2
C                                                                        QDFT  3
C     IORIGN=2 IF THE SOLUTION IS TO BE FORCED THROUGH THE ORIGIN,0,0    QDFT  4
C     FITS DATA TO THE EQN. Y=A + B*X + C*X**2                           QDFT  5
C                                                                        QDFT  6
      IF(IORIGN .NE. 2) GO TO 10                                         QDFT  7
      NDP=NDP+1                                                          QDFT  8
      XQ(NDP)=0.0                                                        QDFT  9
      YQ(NDP)=0.0                                                        QDFT 10
   10 CONTINUE                                                           QDFT 11
      DO 20 I=1,NDP                                                      QDFT 12
   20 SIG(I)=0.0                                                         QDFT 13
      MOD=0                                                              QDFT 14
      NORD=2                                                             QDFT 15
      CALL POLFIT(XQ,YQ,SIG,NDP,NORD,MOD,AA,CHSQ)                        QDFT 16
      A=AA(1)                                                            QDFT 17
      B=AA(2)                                                            QDFT 18
      C=AA(3)                                                            QDFT 19
      SUM=0.0                                                            QDFT 20
      DO 30 I=1,NDP                                                      QDFT 21
      DIFF=YQ(I)-A-B*XQ(I)-C*XQ(I)**2.0                                  QDFT 22
      SUM=SUM+ (ABS(DIFF))**2.0                                          QDFT 23
   30 CONTINUE                                                           QDFT 24
      FIT=SQRT(SUM)/(NDP-3)                                              QDFT 25
      IF(IORIGN .EQ. 2) NDP=NDP-1                                        QDFT 26
      RETURN                                                             QDFT 27
      END                                                                QDFT 28
      SUBROUTINE POLFIT(X,Y,SIGMAY,NPTS,NORDER,MODE,A,CHISQR)            PLFT  1
C                                                                        PLFT  2
C                                                                        PLFT  3
C     SUBPROGRAM TO FIT PAIRS OF DATA POINTS TO A LEAST SQUARES POLYNOMI PLFT  4
C     UP TO ORDER 10. MAXIMUM NUMBER OF PAIRS OF DATA POINTS IS LIMITED  PLFT  5
C     ONLY BY MAIN CALLING PROGRAM. THE ARGUMENTS ARE AS FOLLOWS.        PLFT  6
C                                                                        PLFT  7
C     X = ARRAY NAME OF INDEPENDENT VARIABLE                             PLFT  8
C                                                                        PLFT  9
C     Y = ARRAY NAME OF DEPENDENT VARIABLE                               PLFT 10
C                                                                        PLFT 11
C     SIGMAY = ARRAY NAME FOR STANDARD DEVIATIONS ABOUT 'Y'              PLFT 12
C                                                                        PLFT 13
C     NPTS = NUMBER OF PAIRS OF DATA POINTS                              PLFT 14
C                                                                        PLFT 15
C     NORDER = ORDER OF POLYNOMIAL TO BE FITTED TO DATA                  PLFT 16
C                                                                        PLFT 17
C     MODE - DETERMINES METHOD OF WEIGHTING LEAST-SQUARES FIT            PLFT 18
C            +1 (INSTRUMENTAL) WEIGHT(I)=1./SIGMA(Y)**2                  PLFT 19
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C          0 (NO WEIGHTING) WEIGHT(I)=1.                                    PLFT 20
C         -1 (STATISTICAL) WEIGHT(I)=1./Y(I)                                PLFT 21
C                                                                            PLFT 22
C   A - ARRAY NAME FOR COEFFICIENTS OF POLYNOMIAL                            PLFT 23
C                                                                            PLFT 24
C   CHISQR - REDUCED CHI SQUARE FOR FIT                                      PLFT 25
C                                                                            PLFT 26
C   CALLING PROGRAM SHOULD DIMENSION 'X', 'Y', AND 'SIGMAY' AT LEAST         PLFT 27
C   'NPTS', AND 'A' AS 10.                                                   PLFT 28
C                                                                            PLFT 29
C   DATA ARE FIT TO A POLYNOMIAL OF SPECIFIED ORDER, 'NORDER'.               PLFT 30
C                                                                            PLFT 31
    DOUBLE PRECISION SUMX(19),SUMY(10),ARRAY(10,10),XTERM,YTERM,             PLFT 32
   1CHISQ                                                                    PLFT 33
    DIMENSION X(1),Y(1),SIGMAY(1),A(1)                                       PLFT 34
C                                                                            PLFT 35
C        ACCUMULATE WEIGHTED SUMS                                            PLFT 36
C                                                                            PLFT 37
    NTERMS=NORDER+1                                                          PLFT 38
    NMAX=2*NTERMS-1                                                          PLFT 39
    DO 1 N=1,NMAX                                                            PLFT 40
  1 SUMX(N)=0.                                                               PLFT 41
    DO 2 J=1,NTERMS                                                          PLFT 42
  2 SUMY(J)=0.                                                               PLFT 43
    CHISQ=0.                                                                 PLFT 44
    DO 11 I=1,NPTS                                                           PLFT 45
    XI=X(I)                                                                  PLFT 46
    YI=Y(I)                                                                  PLFT 47
    IF(MODE)3,6,7                                                            PLFT 48
  3 IF(YI)5,6,4                                                              PLFT 49
  4 WEIGHT=1./YI                                                             PLFT 50
    GO TO 8                                                                  PLFT 51
  5 WEIGHT=1./(-YI)                                                          PLFT 52
    GO TO 8                                                                  PLFT 53
  6 WEIGHT=1.                                                                PLFT 54
    GO TO 8                                                                  PLFT 55
  7 WEIGHT=1./SIGMAY(I)**2                                                   PLFT 56
  8 XTERM=WEIGHT                                                             PLFT 57
    DO 9 N=1,NMAX                                                            PLFT 58
    SUMX(N)=SUMX(N)+XTERM                                                    PLFT 59
  9 XTERM=XTERM*XI                                                           PLFT 60
    YTERM=WEIGHT*YI                                                          PLFT 61
    DO 10 N=1,NTERMS                                                         PLFT 62
    SUMY(N)=SUMY(N)+YTERM                                                    PLFT 63
 10 YTERM=YTERM*XI                                                           PLFT 64
    CHISQ=CHISQ+WEIGHT*YI*YI                                                 PLFT 65
 11 CONTINUE                                                                 PLFT 66
C                                                                            PLFT 67
C        CONSTRUCT MATRICES AND CALCULATE COEFFICIENTS                       PLFT 68
C                                                                            PLFT 69
    DO 12 J=1,NTERMS                                                         PLFT 70
    DO 12 K=1,NTERMS                                                         PLFT 71
    N=J+K-1                                                                  PLFT 72
 12 ARRAY(J,K)=SUMX(N)                                                       PLFT 73
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      DELTA=DETERM(ARRAY,NTERMS)                                        PLFT 74
      IF(DELTA) 15,13,15                                                PLFT 75
   13 CHISQR=0.                                                         PLFT 76
      DO 14 J=1,NTERMS                                                  PLFT 77
   14 A(J)=0.                                                           PLFT 78
      RETURN                                                            PLFT 79
   15 DO 18 L=1,NTERMS                                                  PLFT 80
      DO 17 J=1,NTERMS                                                  PLFT 81
      DO 16 K=1,NTERMS                                                  PLFT 82
      N=J+K-1                                                           PLFT 83
   16 ARRAY(J,K)=SUMX(N)                                                PLFT 84
   17 ARRAY(J,L)=SUMY(J)                                                PLFT 85
   18 A(L)=DETERM(ARRAY,NTERMS)/DELTA                                   PLFT 86
C                                                                       PLFT 87
C          CALCULATE CHI SQUARE                                         PLFT 88
C                                                                       PLFT 89
      DO 19 J=1,NTERMS                                                  PLFT 90
      CHISQ=CHISQ-2.*A(J)*SUMY(J)                                       PLFT 91
      DO 19 K=1,NTERMS                                                  PLFT 92
      N=J+K-1                                                           PLFT 93
   19 CHISQ=CHISQ+A(J)*A(K)*SUMX(N)                                     PLFT 94
      FREE=NPTS-NTERMS                                                  PLFT 95
      CHISQR=CHISQ/FREE                                                 PLFT 96
      RETURN                                                            PLFT 97
      END                                                               PLFT 98
                                                                        PLFT 99
C                                                                       DTRM  1
      FUNCTION DETERM(ARRAY,NORDER)                                     DTRM  2
C                                                                       DTRM  3
C                                                                       DTRM  4
C     FUNCTION SUBPROGRAM TO RETURN THE VALUE OF A DETERMINANT          DTRM  5
C                                                                       DTRM  6
C     CAUTION - THIS SUBPROGRAM DESTROYS THE INPUT MATRIX ARRAY         DTRM  7
C                                                                       DTRM  8
C     ARGUMENTS ARE AS FOLLOWS.                                         DTRM  9
C                                                                       DTRM 10
C     ARRAY - MATRIX WHOSE DETERMINANT IS SOUGHT, MAY BE DIMENSIONED    DTRM 11
C             BY CALLING PROGRAM TO A MAXIMUM OF 10 X 10.               DTRM 12
C                                                                       DTRM 13
C     NORDER - ORDER OF DETERMINANT, (DEGREE OF MATRIX)                 DTRM 14
C                                                                       DTRM 15
      DOUBLE PRECISION ARRAY(10,10),SAVE                                DTRM 16
      DETERM=1.                                                         DTRM 17
      DO 8 K=1,NORDER                                                   DTRM 18
C                                                                       DTRM 19
C          INTERCHANGE COLUMNS IF DIAGONAL IS ZERO                      DTRM 20
C                                                                       DTRM 21
      IF(ARRAY(K,K)) 5,1,5                                              DTRM 22
    1 DO 2 J=K,NORDER                                                   DTRM 23
      IF(ARRAY(K,J)) 3,2,3                                              DTRM 24
    2 CONTINUE                                                          DTRM 25
      DETERM=0.                                                         DTRM 26
      RETURN                                                            DTRM 27
    3 DO 4 I=K,NORDER                                                   DTRM 28
      SAVE=ARRAY(I,J)
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      ARRAY(I,J) =ARRAY(I,K)                                                    DTRM 29
    4 ARRAY(I,K) =SAVE                                                          DTRM 30
      DETERM=-DETERM                                                            DTRM 31
                                                                                DTRM 32
C          SUBTRACT ROW K FROM LOWER ROWS TO GET A DIAGONAL MATRIX              DTRM 33
                                                                                DTRM 34
    5 DETERM=DETERM*ARRAY(K,K)                                                  DTRM 35
      IF(K-NORDER) 6,8,8                                                        DTRM 36
    6 K1=K+1                                                                    DTRM 37
      DO 7 I=K1,NORDER                                                          DTRM 38
      DO 7 J=K1,NORDER                                                          DTRM 39
    7 ARRAY(I,J) =ARRAY(I,J) -ARRAY(I,K) *ARRAY(K,J) /ARRAY(K,K)                DTRM 40
    8 CONTINUE                                                                  DTRM 41
      RETURN                                                                    DTRM 42
      END                                                                       DTRM 43
      SUBROUTINE RDPLOT(COMNT,NCT)                                              RDPL  1
      DIMENSION COMNT(240)                                                      RDPL  2
      DATA END/'END '/                                                          RDPL  3
      DO 10 I=1,10                                                              RDPL  4
      N=(I-1)*20+1                                                              RDPL  5
      NN=N+19                                                                   RDPL  6
      READ(5,15) (COMNT(NNI),NNI=N,NN)                                          RDPL  7
      IF( COMNT(N) .EQ. END) GO TO 20                                           RDPL  8
   15 FORMAT(20A4)                                                              RDPL  9
   10 CONTINUE                                                                  RDPL 10
   20 NCT=I-1                                                                   RDPL 11
      RETURN                                                                    RDPL 12
      END                                                                       RDPL 13
      SUBROUTINE REGLNR( Y,X,NDP,SLOPE,B,FIT)                                   RGLN  1
C     REGLNR PERFORMS A LINEAR REGRESSION ON Y-X DATA PAIRS AND RETURNS         RGLN  2
C                                                                               RGLN  3
C     THE SLOPE,INTERCEPT(B), AND DEGREE OF FIT TO THE MAIN PROGRAM. FOR        RGLN  4
C                                                                               RGLN  5
C     FIT=+ OR - 1.0 , THE FIT IS PERFECT. FOR FIT=0.0 A STRAIGHT LINE          RGLN  6
C                                                                               RGLN  7
C     DOES NOT FIT THE DATA. REGLNR IS NOW DIMENSIONED FOR 50 DATA PAIRS        RGLN  8
C                                                                               RGLN  9
      DIMENSION X(50),Y(50)                                                     RGLN 10
      XSUM=0.0                                                                  RGLN 11
      YSUM=0.0                                                                  RGLN 12
      DO 20 I=1,NDP                                                             RGLN 13
      YSUM=YSUM + Y(I)                                                          RGLN 14
   20 XSUM=XSUM + X(I)                                                          RGLN 15
C                                                                               RGLN 16
      YBAR=YSUM/NDP                                                             RGLN 17
      XBAR=XSUM/NDP                                                             RGLN 18
                                                                                RGLN 19
      SLOPEN=0.0                                                                RGLN 20
      SLOPED=0.0                                                                RGLN 21
      FITRMY=0.0                                                                RGLN 22
C                                                                               RGLN 23
      DO 30 II=1,NDP                                                            RGLN 24
C                                                                               RGLN 25
      XDIFF=X(II) - XBAR                                                        RGLN 26
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      YDIFF=Y(II) - YBAR                                                    RGLN 27
C                                                                           RGLN 28
      SLOPEN= SLOPEN +(XDIFF * YDIFF)                                       RGLN 29
      SLOPED= SLOPED + XDIFF**2                                             RGLN 30
      FITRMY= FITRMY + YDIFF**2                                             RGLN 31
   30 CONTINUE                                                              RGLN 32
C                                                                           RGLN 33
      SLOPE= SLOPEN/SLOPED                                                  RGLN 34
C                                                                           RGLN 35
      FITN= SLOPEN                                                          RGLN 36
      FITRMX= SLOPED                                                        RGLN 37
      FITD= SQRT(FITRMX* FITRMY)                                            RGLN 38
                                                                            RGLN 39
      FIT= FITN/FITD                                                        RGLN 40
C                                                                           RGLN 41
      B= YBAR - SLOPE * XBAR                                                RGLN 42
C                                                                           RGLN 43
      RETURN                                                                RGLN 44
      END                                                                   RGLN 45
      FUNCTION F0CO2 (FCO2)                                                 F0C2  1
      F0CO2=(1.484*0.74/1.00)*FCO2                                          F0C2  2
      RETURN                                                                F0C2  3
      END                                                                   F0C2  4
      FUNCTION F002 (FO2)                                                   F002  1
      F002=(1.38*1.00/1.00)*FO2                                             F002  2
      RETURN                                                                F002  3
      END                                                                   F002  4
      RETURN                                                                F002  3
      END                                                                   F002  4
      FUNCTION P0RT (PRT)                                                   P0RT  1
      COMMON P0M,P0B,P0CIRM,P0CIRB                                          P0RT  2
      P0RT= P0M*PRT + P0B                                                   P0RT  3
      RETURN                                                                P0RT  4
      END                                                                   P0RT  5
      FUNCTION P0IRRT (PRT)                                                 P0RR  1
      COMMON P0M,P0B,P0CIRM,P0CIRB                                          P0RR  2
      P0IRRT=P0CIRM*PRT + P0CIRB                                            P0RR  3
      RETURN                                                                P0RR  4
      END                                                                   P0RR  5
      FUNCTION T0PYR (TPYR)                                                 T0PY  1
      COMMON P0M,P0B,P0CIRM,P0CIRB,T0M,T0B                                  T0PY  2
      T0PYR=T0M*TPYR + T0B                                                  T0PY  3
      RETURN                                                                T0PY  4
      END                                                                   T0PY  5
C                                                                           T0PY  6
      SUBROUTINE GENPLT(X,Y,NPTS,LC,COMNT,NC,XSCL,XFDIV,YSCL,YFDIV,XD,YDGNPL  1
     2 )                                                                    GNPL  2
C                                                                           GNPL  3
C        THIS SUBROUTINE WILL PLOT X,Y DATA IN A LINEAR FORMAT              GNPL  4
C        SCALED TO THE ARRAY LIMITS                                         GNPL  5
C                                                                           GNPL  6
C                                                                           GNPL  7
C       DIMENSION X AND Y IN CALLING PROGRAM AT LEAST NPTS+2                GNPL  8
C       THE ARRARY COMNT SHOULD BE DIMENSION FOR AT LEAT 240                GNPL  9
C       IN THE CALLING PROGRAM                                              GNPL 10
C                                                                           GNPL 11
```

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C                                                                       GNPL 12
C       DEFAULT FOR PLOT DIMENSIONS ARE 8.5 X 11                        GNPL 13
C                                                                       GNPL 14
C       A 77 IN THE LC INPUT OVERLAYS PLOTS                             GNPL 15
C                                                                       GNPL 16
C       'LC'  LINE CONTROL VALUES                                       GNPL 17
C            LC .GT. 0---LINE AND SYMBOLS                               GNPL 18
C            LC .EQ. 0---LINE ONLY                                      GNPL 19
C            LC .LT. 0---SYMBOLS ONLY                                   GNPL 20
C       THE ABSOLUTE VALUE OF LC DETERMINES THE SPACING OF THE          GNPL 21
C       SYMBOLS,  IF LC EQUALS 4 EVERY FOURTH SYMBOL IS PLOTED          GNPL 22
C                                                                       GNPL 23
C       'PC' IS THE PLOT CONTROL CHARACTER                              GNPL 24
C           PC = 0  PRODUCES A LINEAR PLOT                              GNPL 25
C           PC = 1  PRODUCES A SEMILOG PLOT , LINEAR IN X               GNPL 26
C           PC = 2  PRODUCES A LOG-LOG PLOT                             GNPL 27
C           PC = 3  PRODUCES A SEMILOG PLOT , LINEAR IN Y               GNPL 28
C                                                                       GNPL 29
      DIMENSION X(1),Y(1),COMNT(240),A(5),B(5),ISYM(15),D(3),C(5)       GNPL 30
      INTEGER PC                                                        GNPL 31
      REAL*8 DAT1, TIME                                                 GNPL 32
      DATA C/'LIN ','SLGY','LGLG','SLGX','SMOT'/                        GNPL 33
      DATA DXD,DYD,Z,ONE,HLF,XH/8.5,11.,1.0E-10,1.0,0.5,0.140/          GNPL 34
      DATA ISYM/11,14,1,2,3,4,5,6,7,8,9,10,00,12,13/                    GNPL 35
      DATA A,B/5*0.0,5*0.0/, BLANK/'    '/                              GNPL 36
      DATA FLIP /'FLIP'/                                                GNPL 37
C                                                                       GNPL 38
C         MAXIMUM PLOT DIMENSIONS ARE 120 X 28 INCHES                   GNPL 39
C                                                                       GNPL 40
      IF((LC .NE. 77) .AND. (COMNT(239) .EQ. FLIP))  LC = - 1           GNPL 41
      N=NPTS                                                            GNPL 42
      T = COMNT(240)                                                    GNPL 43
      PC = 0                                                            GNPL 44
      DO 20  I=1,3                                                      GNPL 45
      IF(T .EQ. C(I+1))  PC = I                                         GNPL 46
   20 CONTINUE                                                          GNPL 47
      IF(LC .EQ. 77)  PC = SPC                                          GNPL 48
C                                                                       GNPL 49
C         NEGATIVE VALUES ARE NOT ALLOWED FOR LOG AXIS VARIABLES        GNPL 50
C         NEGATIVE VALUES AARE SET EQUAL TO +0.0                        GNPL 51
C                                                                       GNPL 52
      ZERO = 1.0E-50                                                    GNPL 53
      DO 42  I=1,N                                                      GNPL 54
      IF((PC .GE. 2) .AND. (X(I) .LT. ZERO))  X(I) = ZERO               GNPL 55
      IF((Y(I) .LT. ZERO) .AND.   ((PC .EQ. 1) .OR. (PC .EQ. 2)))      GNPL 56
     &  Y(I) = ZERO                                                     GNPL 57
   42 CONTINUE                                                          GNPL 58
      IF(LC .EQ. 77)   GO TO 10                                         GNPL 59
      IF((XD .LT. Z) .OR. (XD .GT. 120.0))  XD = DXD                    GNPL 60
      IF((YD .LT. Z) .OR. (YD .GT. 36.0))  YD =DYD                      GNPL 61
      IF(XD .LT. Z)  XD=DXD                                             GNPL 62
      IF(YD .LT. Z)  YD=DYD                                             GNPL 63
C                                                                       GNPL 64
C         DRAW A BOX AROUND THE PLOT PERIMETER WITH A * AT EACH CORNER  GNPL 65
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C                                                                       GNPL 66
      CALL PLOT(Z,Z,-3)                                                 GNPL 67
      A(2) = XD                                                         GNPL 68
      A(3) = XD                                                         GNPL 69
      B(3) = YD                                                         GNPL 70
      B(4) = YD                                                         GNPL 71
      DO 1  I=1,5                                                       GNPL 72
      CALL PLOT(A(I),B(I),2)                                            GNPL 73
      CALL SYMBOL(A(I),B(I),XH,ISYM(12),Z,-1)                           GNPL 74
    1 CONTINUE                                                          GNPL 75
C                                                                       GNPL 76
C         SCALE DATA                                                    GNPL 77
                                                                        GNPL 78
      AXLX = XD - 2.5                                                   GNPL 79
      AXLY = YD - 4.0                                                   GNPL 80
      N = NPTS                                                          GNPL 81
      CALL PLOT(2.0,3.0,-3)                                             GNPL 82
C                                                                       GNPL 83
C         XSCL AND YSCL FOR LOG AXIS INPUT ARE THE NUMBER OF CYCLES     GNPL 84
C         IN THE PROGRAM THEY ARE CONVERTED TO THE NUMBER OF CYCLES/IN  GNPL 85
C                                                                       GNPL 86
C                                                                       GNPL 87
C         LIMIT ON THE MAXIMUM NUMBER OF CYCLES PER INCH IS TWO         GNPL 88
C                                                                       GNPL 89
      IF((XSCL .LT. Z) .AND. (PC .LE. 1))  CALL SCALE(X,AXLX,N,1)       GNPL 90
      IF((XSCL .LT. Z) .AND. (PC .GE. 2))  CALL SCALG(X,AXLX,N,1)       GNPL 91
      IF(PC .GE. 2)  XSCL = XSCL/AXLX                                   GNPL 92
      IF(XSCL .GT. Z)  X(N+1) = XFDIV                                   GNPL 93
      IF(XSCL .GT. Z)  X(N+2) = XSCL                                    GNPL 94
      IF((PC .GE. 2) .AND. (X(N+2) .GT. 2.0))   WRITE(6,24)             GNPL 95
   24 FORMAT(1H1///'     PLOT BYPASSED DUE TO LOG AXIS LIMIT OF NO',    GNPL 96
     &  ' MORE THAN TWO CYCLES PER INCH----CHECK INPUT DATA $$$')       GNPL 97
      IF((PC .GE. 2) .AND. (X(N+2) .GT. 2.0))  GO TO 14                 GNPL 98
      IF((YSCL .LT. Z) .AND. ((PC .EQ. 0) .OR. (PC .EQ. 3)))  CALL SCALEGNPL 99
     & (Y,AXLY,N,1)                                                     GNPL100
      IF((YSCL .LT. Z) .AND. ((PC .EQ. 1) .OR. (PC .EQ. 2)))  CALL SCALGGNPL101
     & (Y,AXLY,N,1)                                                     GNPL102
      IF((PC .EQ. 1) .OR. (PC .EQ. 2))  YSCL = YSCL/AXLY                GNPL103
      IF (YSCL .GT. Z)  Y(N+1) = YFDIV                                  GNPL104
      IF(YSCL .GT. Z)  Y(N+2) = YSCL                                    GNPL105
      IF(((PC .EQ. 1) .OR. (PC .EQ. 2)) .AND. (Y(N +2) .GT. 2.0) )      GNPL106
     &  WRITE(6,24)                                                     GNPL107
      IF(((PC .EQ. 1) .OR. (PC .EQ. 2)) .AND. (Y(N +2) .GT. 2.0) )      GNPL108
     &  GO TO 14                                                        GNPL109
      IF((PC .GE. 2) .AND. (X(N+1)  .LT. ZERO))  X(N+1) = ZERO          GNPL110
      IF(((PC .EQ. 1) .OR.  (PC .EQ. 2)) .AND. (Y(N+1) .LT. ZERO))      GNPL111
     &  Y(N+1) = ZERO                                                   GNPL112
                                                                        GNPL113
C         SAVE THE SCALE FACTORS FROM THE LAST PLOT                     GNPL114
C                                                                       GNPL115
      SPC = PC                                                          GNPL116
      SXF = X(N+1)                                                      GNPL117
      SYF = Y(N+1)                                                      GNPL118
      SXS = X(N+2)                                                      GNPL119
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      SYS = Y(N+2)                                                      GNPL120
      SXD =XD                                                           GNPL121
      SYD = YD                                                          GNPL122
      NCS = NC                                                          GNPL123
      LCS = LC                                                          GNPL124
   11 IF(NPTS .EQ. 0)  NPTS = N                                         GNPL125
      N = NPTS                                                          GNPL126
      IF(LC .NE. 77)  GO TO 13                                          GNPL127
      X(N+1) = SXF                                                      GNPL128
      Y(N+1) = SYF                                                      GNPL129
      X(N+2) = SXS                                                      GNPL130
      Y(N+2) = SYS                                                      GNPL131
      PC = SPC                                                          GNPL132
      GO TO 12                                                          GNPL133
   13 CONTINUE                                                          GNPL134
C                                                                       GNPL135
C        DRAW AXIS---COMPLETE TWO OPEN SIDES WITH LINES                 GNPL136
C                                                                       GNPL137
C                                                                       GNPL138
C        IF NUMBER OF COMMENTS IS .LE.  TO 0 BLANK OUT ARRAYS           GNPL139
C                                                                       GNPL140
C                                                                       GNPL141
      IF(NC .GT. 0)  GO TO 4                                            GNPL142
      DO 5  I=1,58                                                      GNPL143
      COMNT(I) = BLANK                                                  GNPL144
    5 CONTINUE                                                          GNPL145
    4 CONTINUE                                                          GNPL146
C                                                                       GNPL147
C        THE FIRST TWO COMMENT CARDS CONTAIN THE AXIS  INFORMATION      GNPL148
C        THESE CARDS ARE LIMITED TO 20 CHARACTERS EACH                  GNPL149
C                                                                       GNPL150
C        REGULAR COMMENT CARDS MAY CONTAIN UP TO 80 CHARACTERS          GNPL151
C                                                                       GNPL152
      IF(PC .NE. 0)  GO TO 21                                           GNPL153
      CALL AXIS(Z,Z,COMNT(  1),-20,AXLX,Z,X(N+1),X(N+2))                GNPL154
      CALL AXIS(Z,Z,COMNT( 21), +20,AXLY,90.0,Y(N+1),Y(N+2))            GNPL155
      GO TO 30                                                          GNPL156
   21 IF(PC .NE. 1)  GO TO 22                                           GNPL157
      CALL AXIS(Z,Z,COMNT(  1),-20,AXLX,Z,X(N+1),X(N+2))                GNPL158
      CALL LGAXS(Z,Z,COMNT( 21), +20,AXLY,90.0,Y(N+1),Y(N+2))           GNPL159
      GO TO 30                                                          GNPL160
   22 IF(PC .NE. 2)  GO TO 23                                           GNPL161
      CALL LGAXS(Z,Z,COMNT(  1),-20,AXLX,Z,X(N+1),X(N+2))               GNPL162
      CALL LGAXS(Z,Z,COMNT( 21), +20,AXLY,90.0,Y(N+1),Y(N+2))           GNPL163
      GO TO 30                                                          GNPL164
   23 CONTINUE                                                          GNPL165
      CALL LGAXS(Z,Z,COMNT(  1),-20,AXLX,Z,X(N+1),X(N+2))               GNPL166
      CALL AXIS(Z,Z,COMNT(  21), +20,AXLY,90.0,Y(N+1),Y(N+2))           GNPL167
   30 CONTINUE                                                          GNPL168
      CALL PLOT(AXLX,Z,3)                                               GNPL169
      CALL PLOT(AXLX,AXLY,2)                                            GNPL170
      CALL PLOT(Z,AXLY,2)                                               GNPL171
   12 CONTINUE                                                          GNPL172
C                                                                       GNPL173
C        CHECK FOR PLOT OVERFLOW AND UNDERFLOW AFTER FIRST DATA SET
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C       IF EXTENT CONDITION IS DETECTED REDEFINE DATA POINT                GNPL174
C       TO EXTREME VALUE SO THAT IT IS PLOTTED ON AN AXIS                  GNPL175
C                                                                          GNPL176
C
      XMIN = X(N+1)                                                        GNPL177
      YMIN = Y(N+1)                                                        GNPL178
      XX = X(N+2)                                                          GNPL179
      YY = Y(N+2)                                                          GNPL180
      TEN = 10.00                                                          GNPL181
      XMAX = AXLX*XX + XMIN                                                GNPL182
      IF(PC .GE. 2)  XMAX = (TEN**(AXLX*XX))*(XMIN)                        GNPL183
      YMAX = AXLY*YY + YMIN                                                GNPL184
      IF((PC .EQ. 1) .OR. (PC .EQ. 2))  YMAX = (TEN**(AXLY*YY))*(YMIN)     GNPL185
      DO 65  I=1,N                                                         GNPL186
      PX = (X(I) - XMIN)/XX                                                GNPL187
      PY = (Y(I) - YMIN)/YY                                                GNPL188
      IF(PC .GE. 2)  PX = ALOG10(X(I)/XMIN)/XX                             GNPL189
      IF((PC .EQ. 1) .OR. (PC .EQ. 2))  PY = ALOG10(Y(I)/YMIN)/YY          GNPL190
      IF(PX .GT. AXLX)  X(I) = XMAX                                        GNPL191
      IF(PY .GT. AXLY)  Y(I) = YMAX                                        GNPL192
      IF(PX .LT. Z)  X(I) = XMIN                                           GNPL193
      IF(PY .LT. Z)  Y(I) = YMIN                                           GNPL194
   65 CONTINUE                                                             GNPL195
C                                                                          GNPL196
C         PLOT DATA                                                        GNPL197
C                                                                          GNPL198
      IF( LC .NE. 77)  MM = 1                                              GNPL199
      IF(LC  .EQ. 77)  MM = MM +1                                          GNPL200
      IF( MM .GT. 15) GO TO 14                                             GNPL201
      IF(LC .EQ. 77)  LX = LCS                                             GNPL202
      IF((LC.EQ.77).AND.(COMNT(239).EQ.FLIP)) GO TO 345                    GNPL203
   350 CONTINUE                                                            GNPL204
      IF(LC .NE. 77)  LX = LC                                              GNPL205
C                                                                          GNPL206
      K = 1                                                                GNPL207
      IF(COMNT(240) .EQ. C(5))  K = - 1                                    GNPL208
      IF(PC .EQ. 0)  CALL FLINE(X,Y,K*N,1,LX,ISYM(MM) )                    GNPL209
      IF(PC .GT. 0)  CALL LGLIN(X,Y,N,1,LX,ISYM(MM),2-PC )                 GNPL210
                                                                           GNPL211
      IF(LC .EQ. 77)  GO TO 15                                             GNPL212
C                                                                          GNPL213
C         WRITE COMMENTS UNDER PLOT                                        GNPL214
C                                                                          GNPL215
      IF(XD .LT. 8)  CALL FACTOR(XD/8.5)                                   GNPL216
      XH = 0.090                                                           GNPL217
      IF(NC .LE. 2)  GO TO 7                                               GNPL218
      YI = -1.5*XH                                                         GNPL219
      YS =-1.40                                                            GNPL220
      IF(NC .GT. 10)  NC =10                                               GNPL221
      DO 2  J=3,NC                                                         GNPL222
      M=20*(J-1)                                                           GNPL223
      CALL SYMBOL(-ONE,YS,XH,COMNT(M+1),Z,80)                              GNPL224
      YS = YS + YI                                                         GNPL225
    2 CONTINUE                                                             GNPL226
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    7 CONTINUE                                                              GNPL227
C                                                                           GNPL228
C       WRITE SYMBOL AND NUMBER IN UPPER RIGHT HAND CORNER OF PLOT          GNPL229
C                                                                           GNPL230
   15 XNUM = MM                                                             GNPL231
      YS = FLOAT(MM-1)*(1.5*XH)                                             GNPL232
      IF((COMNT(239) .EQ. FLIP) .AND. (LX .EQ. 0)) GO TO 17                 GNPL233
      CALL NUMBER(AXLX-0.7    ,AXLY-0.5 -YS ,XH,  XNUM     ,Z,-1)           GNPL234
      CALL SYMBOL(999.0, AXLY-0.5-YS,XH,'- ',Z,2)                           GNPL235
      CALL SYMBOL(999., AXLY-0.5-YS+XH/2.0, XH,ISYM(MM),Z,-1)               GNPL236
   17 CONTINUE                                                              GNPL237
      IF(LC .EQ. 77)  GO TO 14                                              GNPL238
C                                                                           GNPL239
C       WRITE DATE AND TIME ON PLOT                                         GNPL240
C                                                                           GNPL241
      YS=-2.9                                                               GNPL242
       CALL DATE(DAT1)                                                      GNPL243
      CALL TIMEOD(TIME)                                                     GNPL244
      CALL SYMBOL(3.0,YS   , XH,'DATE  ',Z,6)                               GNPL245
       CALL SYMBOL(999.,YS,XH,DAT1,Z,+8)                                    GNPL246
       CALL SYMBOL(999.,YS,XH,'      ',Z,6)                                 GNPL247
       CALL SYMBOL(999.,YS,XH,TIME,Z,8)                                     GNPL248
      CALL FACTOR(1.000000)                                                 GNPL249
C                                                                           GNPL250
C       MOVE PLOT ORIGIN                                                    GNPL251
C                                                                           GNPL252
   14 CONTINUE                                                              GNPL253
      CALL PLOT(XD,-3.0,-3)  .                                              GNPL254
      RETURN                                                                GNPL255
   10 CONTINUE                                                              GNPL256
      PC = SPC                                                              GNPL257
      XD = SXD                                                              GNPL258
      YD = SYD                                                              GNPL259
      CALL PLOT(-XD,3.0,-3)                                                 GNPL260
      GO TO 11                                                              GNPL261
C                                                                           GNPL262
C       USE THE SCALE FACTORS FOR THE FIRST PLOT ON AN OVERLAY              GNPL263
C                                                                           GNPL264
  345 IF(LX.EQ.-1)GO TO 347                                                 GNPL265
      LX=-1                                                                 GNPL266
      LCS=-1                                                                GNPL267
      GO TO 350                                                             GNPL268
  347 LX=0                                                                  GNPL269
      LCS=0                                                                 GNPL270
      GO TO 350                                                             GNPL271
      END                                                                   GNPL272
```

TABLE AP VII-1

RUN NUMBER 1
NO. DATA POINTS 25
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 800.0000
O2 FEED RATE 40.000000 CC/MINUTE
BASELINE TRANSMITTANCE 0.8650

TIME (MINUTES)	RELATIVE TRANSMITTANCE	REACTOR PRESSURE METER (TORR)	PYROMETER METER (DEG. CELSIUS)
1.0000	0.8100	6.4000	0.0
2.0000	0.7800	6.6000	0.0
3.0000	0.7750	6.8000	114.0000
4.0000	0.7670	6.9000	120.0000
5.0000	0.7600	7.0000	128.0000
6.0000	0.7550	7.0000	141.0000
7.0000	0.7400	7.2000	150.0000
8.0000	0.7300	7.3500	160.0000
9.0000	0.7200	7.5000	167.0000
10.0000	0.7100	7.5000	174.0000
11.0000	0.7000	7.6000	190.0000
12.0000	0.7000	7.7000	194.0000
13.0000	0.7000	7.7000	198.0000
14.0000	0.7000	7.7000	200.0000
15.0000	0.6950	7.8000	204.0000
16.0000	0.6950	7.8000	206.0000
17.0000	0.6850	7.8000	208.0000
18.0000	0.6850	7.8000	210.0000
19.0000	0.6850	7.8000	212.0000
20.0000	0.6850	7.8000	214.0000
21.0000	0.6850	7.8000	215.0000
22.0000	0.6850	7.8000	216.0000
23.0000	0.6850	7.8000	217.0000
24.0000	0.6850	7.8000	218.0000
25.0000	0.6850	7.8000	219.0000

TABLE AP VII-2

RUN NUMBER 2
NO. DATA POINTS 20
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 200.0000
02 FEED RATE 40.000000 CC/MINUTE
BASELINE TRANSMITTANCE 0.8950

TIME (MINUTES)	RELATIVE TRANSMITTANCE	REACTOR PRESSURE METER (TORR)	PYROMETER METER (DEG. CELSIUS)
1.0000	0.8800	6.1000	0.0
2.0000	0.8700	6.5000	0.0
3.0000	0.8700	6.7000	0.0
4.0000	0.8700	6.8000	0.0
5.0000	0.8650	6.8500	0.0
6.0000	0.8650	6.8500	0.0
8.0000	0.8600	6.8500	0.0
10.0000	0.8550	6.8500	0.0
12.0000	0.8550	6.8500	0.0
14.0000	0.8500	6.8500	0.0
16.0000	0.8500	6.8500	0.0
18.0000	0.8470	6.8500	0.0
20.0000	0.8470	6.8500	0.0
24.0000	0.8450	6.8500	0.0
28.0000	0.8450	6.8500	0.0
32.0000	0.8420	6.8500	0.0
36.0000	0.8420	6.8500	0.0
40.0000	0.8420	6.8500	0.0
42.0000	0.8420	6.8500	0.0
44.0000	0.8420	6.8500	0.0

TABLE AP VII-3

RUN NUMBER 3
NO. DATA POINTS 22
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 400.0000
O2 FEED RATE 40.000000 CC/MINUTE
BASELINE TRANSMITTANCE 0.9100

TIME (MINUTES)	RELATIVE TRANSMITTANCE	REACTOR PRESSURE METER (TORR)	PYROMETER METER (DEG. CELSIUS)
1.0000	0.8800	6.2000	0.0
2.0000	0.8700	6.6000	0.0
3.0000	0.8650	6.8000	0.0
4.0000	0.8600	6.9000	0.0
5.0000	0.8550	6.8000	0.0
6.0000	0.8500	6.9000	0.0
7.0000	0.8450	6.8000	0.0
8.0000	0.8450	6.9000	0.0
9.0000	0.8450	6.8000	0.0
10.0000	0.8400	6.9000	0.0
12.0000	0.8370	6.9000	0.0
14.0000	0.8370	6.9000	108.0000
16.0000	0.8350	6.9000	112.0000
18.0000	0.8200	6.9000	118.0000
20.0000	0.8200	6.9000	122.0000
22.0000	0.8170	6.9000	125.0000
24.0000	0.8150	6.9000	127.0000
26.0000	0.8100	7.0000	128.0000
28.0000	0.8100	7.0000	130.0000
30.0000	0.8050	7.0000	130.0000
32.0000	0.8050	7.0000	134.0000
36.0000	0.8050	7.0000	133.0000
			134.0000

TABLE AP VII-4

RUN NUMBER 4
NO. DATA POINTS 18
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 600.0000
02 FEED RATE 40.000000 CC/MINUTE
BASELINE TRANSMITTANCE 0.9250

TIME (MINUTES)	RELATIVE TRANSMITTANCE	REACTOR PRESSURE METER (TORR)	PYROMETER METER (DEG. CELSIUS)
1.0000	0.8850	6.7000	0.0
2.0000	0.8700	6.8000	0.0
3.0000	0.8650	6.9000	0.0
4.0000	0.8550	7.0000	0.0
5.0000	0.8500	7.0000	0.0
6.0000	0.8450	7.0000	108.0000
7.0000	0.8400	7.0000	115.0000
8.0000	0.8370	7.0000	122.0000
9.0000	0.8350	7.1000	126.0000
10.0000	0.8200	7.2000	132.0000
12.0000	0.8150	7.3000	141.0000
14.0000	0.8100	7.2000	149.0000
16.0000	0.8100	7.3000	153.0000
18.0000	0.8100	7.4000	157.0000
20.0000	0.8100	7.4000	162.0000
22.0000	0.8100	7.5000	166.0000
24.0000	0.8100	7.6000	169.0000
26.0000	0.8100	7.6000	171.0000

TABLE AP VII-5

RUN NUMBER 5
NO. DATA POINTS 17
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 800.0000
02 FEED RATE 22.000000 CC/MINUTE
BASELINE TRANSMITTANCE 0.9300

TIME (MINUTES)	RELATIVE TRANSMITTANCE	REACTOR PRESSURE METER (TORR)	PYROMETER METER (DEG. CELSIUS)
1.0000	0.9100	5.3000	0.0
2.0000	0.8600	5.7000	0.0
3.0000	0.8350	5.8000	110.0000
4.0000	0.8250	6.0000	122.0000
5.0000	0.8100	6.0000	135.0000
6.0000	0.7950	6.0000	146.0000
7.0000	0.7850	6.1000	157.0000
8.0000	0.7800	6.1000	166.0000
10.0000	0.7650	6.1000	180.0000
12.0000	0.7600	6.1000	195.0000
14.0000	0.7500	6.1000	202.0000
18.0000	0.7500	6.1000	212.0000
20.0000	0.7450	6.1000	215.0000
22.0000	0.7450	6.1000	218.0000
24.0000	0.7350	6.1000	219.0000
26.0000	0.7350	6.1000	222.0000
28.0000	0.7350	6.1000	224.0000

TABLE AP VII-6

RUN NUMBER 9
NO. DATA POINTS 19
NUMBER OF WAFERS 20
POWER LEVEL RF WATTS 800.0000
02 FEED RATE 20.000000 CC/MINUTE
BASELINE TRANSMITTANCE 0.9100

TIME (MINUTES)	RELATIVE TRANSMITTANCE	REACTOR PRESSURE METER (TORR)	PYROMETER METER (DEG. CELSIUS)
1.0000	0.8250	4.7000	0.0
2.0000	0.7850	5.1000	0.0
3.0000	0.7800	5.5000	0.0
4.0000	0.7650	5.6000	112.0000
5.0000	0.7500	5.6000	126.0000
6.0000	0.7450	5.7000	140.0000
7.0000	0.7400	5.7000	153.0000
8.0000	0.7300	5.8000	162.0000
9.0000	0.7200	5.8000	171.0000
10.0000	0.7100	5.8000	178.0000
12.0000	0.6900	5.8000	188.0000
14.0000	0.6900	6.0000	199.0000
16.0000	0.6850	6.1000	207.0000
18.0000	0.6850	6.1000	213.0000
20.0000	0.6850	6.2000	217.0000
22.0000	0.6850	6.2000	220.0000
24.0000	0.6850	6.2000	222.0000
26.0000	0.6850	6.2000	223.0000
28.0000	0.6850	6.2000	225.0000

APPENDIX VIII

Sources of Error

During the experiments, radio frequency (rf) interference was noticed in the recording instruments. The rf problem with the thermocouple inserted directly into the plasma has been discussed. Eliminating the interference was not possible, however, the effect was minimized by use of a common mode rejection circuit. Rf interference with the mass flow controller was also experienced. This was not a significant problem because even though the rf shifted the preset flow value, the indicated flow rate always corresponded to the actual flow. For example, with rf power off the flow was preset at 20 cc/min.. When rf power (800 watts) was turned on the controller might change to 30 cc/min.. Although the rf had changed the preset value, the indicated flow , 30 cc/min., was always consistent. This supposition was verified by comparing the system pressure before and after the rf was turned on. The pressure gauges were not affected by rf.

No rf influence was detectable in the infrared pyrometer used to measure wafer temperature. However, from analyzing the data for the 800 watt runs, it appears that there might be a +5 C offset in all of the temperatures above 180 C caused by rf pickup. This pickup even if real is insignificant since it represents an error of only 3%.

VITA

Paul Saunders was born in Woburn, Massachusetts on Sept. 14, 1948 to Mr. and Mrs. Robert J. Saunders. Following public high school, he attended the University of Massachusetts at Amherst from 1966 to 1970, graduating with a Bachelor of Science degree in Chemical Engineering in June 1970. From June of 1970 to the present, he has worked on the processes and equipment for the cleaning, photolithography, diffusion, and ion implantation of silicon semiconductors at Western Electric Co., Allentown, Pennsylvania.